# OPERATIVE NEUROSURGERY

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## WITH EMPHASIS ON PROCEDURES IN TRAUMA

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*Dedicated to*

DOROTHY EILEEN GURDJIAN

*and*

MARJORIE WEBSTER

in appreciation of

Encouragement and Understanding

# Preface

IN THIS volume an effort has been made to give pertinent anatomic, diagnostic and technical information in the execution of certain operative procedures in neurological surgery. In so far as possible, the method of consecutive pages of description and illustration has been used. The material has been divided into four parts; namely, head, spine, sympathetic nervous system, and peripheral nerves. The general subject of neurosurgery has been covered, but emphasis has been laid upon traumatic procedures in neurosurgery.

In the preparation of this book, use has been made of standard anatomical text books, including Gray's Anatomy, Grant's Anatomy, Anson's Anatomy, the Anatomic Volumes by Testut and Latarjet, the Cross-Sectional Anatomy of Eycleshymer and Schoemaker, the books on Peripheral Nerve Injuries by Stookey, Pollock and Davis, Haymaker and Woodhall, and many others. We have summarized in the form of diagrams and other illustrations the anatomic information pertinent to the operative procedure in question. Space has been utilized to describe anatomic structures, not necessarily related to the main theme under discussion. It is felt that these summaries may be of help to the neurosurgical resident, to the general surgeon who may do an occasional neurosurgical operation, as well as other neurosurgeons who may wish to familiarize themselves with the anatomy of the part in question

Standard procedures have been presented. Procedures done in a special manner by neurosurgeons who have found certain abbreviations in technique to be of value, in their hands, are not discussed in this volume. A brief review of the historical development of some of the procedures is also given. It has been impossible to include all of the operative variations in technique pertinent to the management of certain conditions. As they become more standardized they will undoubtedly be discussed and described in the future

This volume has been made possible through the work of many people, and an important member of this group is Miss P. M. LaRiviere, who illustrated the book in its entirety The authors feel that she has been most accurate in her interpretation of the operative procedures discussed. The

illustrations are diagrammatic. They are multiple action and multiple plane drawings rather than static photographic type of records. The illustrations should be used in conjunction with the description of the procedures. Secretarial work, proof reading, and the checking of the bibliography was aided by Miss Helen Waclawek, Miss Madeleine Varani, Mrs. Chloe Brewer, Mrs. Jane Williams, and Mrs. Dorathea McCurdy. The use of the anatomical laboratories and dissection material was made possible through Dean Gordon H. Scott and Professor Ernest D. Gardner and this was of inestimable value in that almost all of the procedures were not only seen in the operating room but also dissected out in the Anatomical Laboratory. Much help was obtained in the dissections by a former resident in neurosurgery, Dr. Ralph E. Dawson.

E. S. G.
J. E. W.

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# Craniotomy—Historical

EARLIER explorations of the surface of the brain were limited to an exposure by means of a trephine. Surgical progress influenced by antisepsis, anesthesia and a knowledge of cerebral localization, however, led in the late nineteenth century to the practicability of exposing a larger area of the brain in treating intracranial disease. Prior to 1889, when Wagner introduced the osteoplastic technique of bone removal and replacement, the skull was opened by straight, curved, crossing or crucial scalp incisions and trepanation or by removal of a portion of bone by means of hand saws of varying types. The area of the skull designed for removal in forming a "permanent window" was outlined. Beginning from the area of trephine, portions of the bone were then removed by means of large bone-biting forceps, all traction being made in an outward direction.

W. Wagner of Königshütte in 1889, reported on "A Temporary Resection of the Skull where Trepanation is to be Performed". "By experimenting on corpses," he stated, "I have tried to work out a method which would make it possible to resect temporarily a piece of desired size from the skull cap without separating it from the soft tissue." An omega type of flap was used with the circle portion of the bone completely chiseled through. One or both legs of the omega were cut and the bridge beneath the scalp broken through. The flap was then turned between the legs of the omega, "with all the soft tissues on it, and it remains linked with the soft tissues covering the skull by medium of a stem which is about 3 cm. wide". Wagner predicted that both the scalp and bone flaps would heal. This procedure was first applied in a patient with a middle meningeal hemorrhage following an extensive skull fracture which later resulted in "exitus lethalis".

It is of historical interest that Francesco Durante, rather than Wagner, probably deserves recognition for first using an osteoplastic flap. In his own words Durante has reported that "beginning with the year 1884, when for the first time I operated upon a sarcoma of the anterior cerebral fossa, I have always made osteocutaneous flaps, which later on were attributed to Wagner. I have always succeeded in causing the bones to grow together. However, from my experiments on animals, I have concluded that the osseous squami lifted with the pericranium facilitates the growing together of the latter although they resorb slowly". Durante used incisions similar to those used at the present time. He reported that for a frontal explora-

# Craniotomy—Historical

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tion, "the incision begins from the glabella and goes up in a vertical way surpassing the line where the hair begins to grow. Then it turns curving toward the left and then down to reach the center of the temporal region at a distance of 2.5 cm. from the zygomatic ridge. In this way a flap is formed and in its shape it resembles a horseshoe, the frontotemporal bone forms thus the base of the flap". Durante used power-driven, circular saws for cutting the bone, and a gouge with a wooden hammer to form the bony opening.

Horsley[32] is reported to have "wasted no time over an osteoplastic flap" (Cushing). After the reflection of the scalp and gaining access to the dura, segments of the bone were removed piece-meal and discarded. Bone was generously removed for exposure of a tumor. If dangerous hemorrhage occurred during this procedure the dura was not opened. Instead, the operation was discontinued and the final stages completed five to seven days later The scalp was closed loosely with sutures which allowed drainage of cerebrospinal fluid. Even later this rapid method was preferred to the osteoplastic method of sparing bone by section of a flap with a hammer, chisel and hand saw.

Various methods of sawing and hammering were used to cut the bone from without inward. In 1897, Obalinsky proposed the use of a flexible wire saw described in the same year by Leonardo Gigli of Florence for obstetrical purposes. The latter reported that "Prof. Obalinsky emphasized the efficiency of my saw as applied in craniotomy. In order to make it more efficient, I have worked out (on cadaver) the technique of the operation as I was convinced that with no other instrument would it be possible to cut out osteoplastic flaps of desired size". Gigli's technique made use of a "sound with a groove" in it having "an almost rectangularly shaped end" A gliding whale bone plate fitted in the sound's groove A disc of bone was removed at one corner of a three-sided flap, the sound inserted, and the gliding whale bone used to pull through "a long, thin, strong thread". The various openings and threads permitted separation of the dura from the skull. Following this step, the wire saw was then applied, substituting for the silk thread, and the bone cut through along three edges, partially sparing the base This allowed section of the bone from within outwards and, thus, lessened the possibility of underlying damage.

Later, the principle of osteoplastic flap was maintained but its execution simplified Usually, two small openings were made in the skull. The sides of a flap of bone were then sectioned by means of bone-cutting forceps of several types, namely, the biting forceps of Montenovesi or Doyen, or with cutting-hook types of forceps, suggested by Dahlgren and DeVilbiss, instruments which cut the bone from within outwards The Gigli saw was tied to a "silk carrier", which in turn was tied to an eye in a grooved director and both were inserted between the skull openings. The Gigli saw was then used across the upper margin of the designed bone flap, cutting the bone on a bevel The base was readily broken. This is a combined method described by DaCosta in 1907

The use of the crowned trephine to make primary openings for a bone flap was replaced by special burrs which were designed by various surgeons, including Hartley and Doyen[199]. The latter suggested a number of helpful instruments which included some intended for manipulation by hand and some which could be used with an electric motor. For trephination a flat perforator with a hand brace was used, this being guarded by means of shoulders which projected from the cutting blade. Conical and spherical burrs were used, which had a protective crown that was adjustable to the thickness of the bone. Special gouges, craniotomy chisels, and sliding saws with protectors, were important additions to the armamentarium for cranial operations. Doyen employed so-called "shutters", or a "temporary craniectomy" of large proportions, describing a "large frontoparietosphenotemporal shutter". Multiple primary openings were made in the area for craniotomy. Section of the external table between the openings was made with a guarded (Doyen) saw of the Scultetus type after measuring the thickness of the bone and setting the protecting guard.

The division of the bone was then completed with a biting forceps, mallet and a chisel. To fracture the base of the flap a hammer and chisel were used. Dr. W. H. Hudson of Atlanta, Georgia, improved the Doyen burrs, and in 1909 Keen[253] reported that the Hudson drills were superior to previous instruments. The Hudson spiral cutting blades resulted in resistance to cutting as the burr reached the dura. These burrs were rapidly accepted and are in general use at the present time. Cushing[77] preferred "the cutting of bone from within method", using the Gigli saw. "Two openings were made at the upper corners of a rectangular flap, the intervening bone being cut with a Gigli saw. If the width of the flap was great, three openings were made. The sides of the flap were cut with the Montenovesi and Dahlgren forceps"

Electrically driven burrs were later employed to make openings similar to those made by hand The bridges of bone between the openings were sectioned in their full thickness, except for two areas, at which only the outer table was cut. These sections were made by a circular driven saw which was protected from cutting the dura. The two bridges of the inner table, which were spared, were sectioned with a mallet and chisel so that the bone flap would not rest upon the brain at closure. The first use of an engine in surgery was made by Harrison Allen in Philadelphia, in 1876, for oral surgery Modifications were made until an improved motor driven "surgical engine" of Cryer, a dentist, was used by Keen[252] in 1893, in an operation for removal of the gasserian ganglion. Cryer stated that he "considered this engine as far in advance of the chisel and mallet in bone surgery as the Pullman car is ahead of the canal boat in traveling". The use of a "fraise", a motor driven spiral osteotome with a button on the end of the tool to protect the dura, was introduced by Cryer in 1897, and Sudeck in 1900. After a primary opening, this instrument could rapidly section the bone for any distance. In 1907 a small motor, enclosed in a sterilizable steel metal casing, with appropriate burrs and saws, was recom-

mended by Hartley and Kenyon to replace the earlier flexible shaft type with remote motor. The present day electrically driven burrs are essentially this type of instrument.

Important refinements by Halsted, Kocher[232] and Cushing[78] have made possible the present day technique in cranial surgery. The speedy one hour operation for a brain tumor, finger or spoon enucleation, packs to control hemorrhage, and loose scalp sutures to allow leakage of spinal fluid, were replaced by a refined but time consuming technique of tumor dissection, careful hemostasis, and layer closure. The progress in surgical technique has continued hand-in-hand with progress in diagnosis and increased knowledge of the physiology of the nervous system.

# Preliminary Considerations

## Diagnostic Aids

IN THE management of patients with intracranial lesions, diagnostic aids deserve review. A few of these will be considered at this time, but in individual situations they will be discussed in greater detail later in this volume.

A careful history is important. If a neurological deficit is already present a history of its onset and progress becomes significant. In traumatic cases a careful short history may be crucial in a decision to use surgical treatment. A history of convulsive phenomena, whether generalized, Jacksonian, or sensory in type; the exact pattern of the attack; the presence of an aura are clinical facts requiring attention. A loss or perversion of olfactory sense; progressive loss of hearing; a history of ataxia, incoordination; visual disturbances; paralysis; etc., may be essential historical data in directing a neurological workup.

The neurological examination should be carried out in detail. Such an examination should also include careful visual field studies; caloric, Barany and audiometer tests; and study of the olfactory sense in selected cases. Intellectual and psychological measurements are useful and sometimes essential, particularly in the surgery for psychoses. The neurological workup usually includes the routine use of spinal puncture in almost all cases. There is minimal danger involved in measuring the cerebrospinal fluid pressure and removing the few cubic centimeters of fluid which have filled the manometer. A study of the cerebrospinal fluid should include a cell count and measurement of the total protein, sugar, chlorides, and serological and colloidal gold tests.

Roentgenology is an indispensable diagnostic aid in neurological surgery. As radiology has advanced, so has the diagnosis of neurological diseases. X-rays, discovered by Roentgen in 1895, were employed first in the detection of fractures. The application of this technique to the skull was soon appreciated. With the introduction of ventriculography[94a] in 1918 by Dandy, followed by encephalography[94], the localization of brain tumors became more precise. Contrast media, used in spinal cord diseases, include lipiodol, and more recently, pantopaque. Angiography, introduced in 1927 by Moniz[310], has only recently gained clinical acceptance in this country. This technique, employing such media as diodrast® and thorotrast® is revealing new possibilities in vascular surgery, as well as aiding in the diagnosis of mass lesions.

Routine survey studies of the skull include usually four or six conventional views, which may be augmented by detail studies if indicated. The value of the survey depends upon the quality of the films made, which in turn is dependent upon the skilled technical ability in the radiology department. Information gained by this single diagnostic procedure may be considerable. Traumatic lesions may be classified as to type of fracture or extent of penetration by a foreign object. Congenital deformities may be visible; the fontanel and sutures widened; the foramina found to be enlarged or eroded; the vault destroyed or distorted; the diploic vascular channels disturbed. A neoplasm in or about the sella turcica may be confirmed or suspected. About ten per cent of gliomatous tumors have associated calcification within the lesion and are thus revealed in the roentgen studies An occasional aneurysm or intracranial abscess may also show calcification in its wall. Calcification of the pineal gland aids in diagnosis If present, displacement in position may be significant. In adult life, fifty per cent of the patients have calcified pineal glands. Bilateral calcifications in the choroid plexus occur in about ten per cent of the patients.

Ventriculography[9,1a] was introduced in 1918 by Dandy, and this has been a preferential diagnostic method since its introduction. It is used particularly if the patient has papilledema or other evidences of increased intracranial pressure Ventriculography is both safe and satisfactory, being performed in the upright position under local anesthesia through parieto-occipital burr openings as illustrated on page 33 The ventricle may be entered, evacuated of cerebrospinal fluid and room air substituted Upright, prone, and supine roentgen studies are then made in order to visualize in detail the ventricular system, using air as a contrast medium. In some instances it may be necessary to introduce air by the lumbar route at the same time that the ventricles have been filled by the ventricular puncture method

A "ventricular estimation" has been of value permitting confirmation of a posterior fossa tumor when tap of the ventricles reveals a symmetrical hydrocephalus. In our experience, routine employment is made of complete ventriculographic studies, regardless of the "estimation", in order to avoid unusual but tragic mistakes

Encephalography was used shortly after the introduction of ventriculography The easier introduction of air into ventricles won favor rapidly. A lumbar puncture needle is introduced into the lumbar sac and with the patient in a sitting position the cerebrospinal fluid is removed and air or oxygen is introduced. Radiological equipment for upright skull studies is useful Complete upright, as well as supine and prone views are made The filling of the various cisterns and the surface subarachnoid pathways is the advantage offered by the encephalogram over the ventriculogram

Cerebral angiography may be done by either a "closed" or "open" method Diodrast® (thirty-five per cent) or thorotrast® is injected into the common or internal carotid artery Employed by the percutaneous or "closed" method, this type of roentgen study has several advantages, including simplicity Local or pentothal anesthesia may be used Disad-

vantages include the occasional untoward reaction to diodrast®, resulting in hemiparesis or hemiplegia. Thorotrast® is radioactive and is not excreted from the body.

The advantages of angiography include the visualization of the vascular lesions which cannot be revealed by pneumoencephalography. Neoplasms involving the anterior fossa, the sphenoid ridge and the chiasm may be outlined by the distortion of the anterior cerebral artery at an earlier phase than by air studies. Traumatic lesions, such as subdural, epidural, intracerebral hematomas may be excluded by this method. This is preferable to the use of exploratory trephine openings.

Although a serial film technique, such as the Fairchild, Sanchez-Perez, etc., is preferable, considerable basic information may be obtained by lateral and anteroposterior views with two injections of the contrast medium. Thorotrast® is the medium preferred in those patients who are acutely ill or of an advanced age.

The use of radioactive isotope studies for the localization of lesions of the central nervous system is becoming better understood. This technique may be preferable to other diagnostic procedures previously used. Its accuracy is reported to be much higher than that of encephalography, or ventriculography. More knowledge of the advantages and disadvantages of this technique is necessary before its diagnostic value can be evaluated.

Electroencephalography has been useful, but in many instances, localization by this means has not been too accurate. Although in many patients with intracranial mass lesions there are abnormal electrical patterns, the exact localization of a mass lesion by this technique is possible in about half of the cases. Abnormal electrical patterns occur in a much higher percentage of cases, but they are not of significant localizing value.

### Anesthesia

Anesthesia is one of the important links in the chain comprising the well-executed neurosurgical operation. The surgeon is less and less required to attend to the patient's physiological state while in the operating room. His attention may be devoted completely to the surgical field with full confidence that a suitably selected anesthesia or a combination of anesthetic agents is skillfully administered; that an adequate exchange of $O_2$ and $CO_2$ is taking place, that blood loss is replaced; that vital signs of distress will be recognized and promptly combated. The neurosurgical era of local anesthesia by infiltration has now progressed into a period of safe anesthetic versatility contributed by the anesthesiologist. By close cooperation between the anesthesiologist and the neurosurgeon, the anesthetist's skill in this type of patient is augmented.

In elective operations upon the head, intratracheal gas-ether is a safe anesthetic in all age groups when skillfully administered, avoiding respiratory obstruction during intubation as well as throughout the operation. Intravenous anesthesia with or without local infiltration by *procaine has* an important place in neurosurgical procedures. Sodium pentothal solution intravenously should be avoided in patients with acute head injuries and

in the very ill patient with an intracranial mass lesion. Intubation is desirable in patients receiving intravenous anesthesia.

Local anesthesia with one-half of one per cent procaine solution infiltration into the operative site, fortified with preoperative medication, has wide applicability in the surgery of the nervous system. The very ill patient with a mass lesion may be operated upon with this technique. Local anesthesia may be used in angiography and pneumoencephalography. It is reported that in 1904, Heidenhain first used a half per cent solution of cocaine with adrenalin for local injection. Procaine was introduced in 1905. Even when general anesthesia is used, local infiltration about the area of incision is helpful for its anesthetic as well as its hemostatic effect. Block infiltration of the supra-orbital and supratrochlear nerves anteriorly and the auriculotemporal nerve, anterior to the ear, may be used in frontotemporal parietal incisions. With a more posterior lesion the greater occipital and posterior auricular nerves may also be blocked posteriorly along the superior nuchal line.

## Position of the Patient During Operation

The position of the patient during operation is important in many neurosurgical procedures. An operating table which can be made into a chair or used as a table, with attachments permitting hyperflexion of the body or hyperextension in the lateral position is advantageous. In our own practice the upright position is commonly used for section of the fifth root by temporal or the occipital route, all posterior fossa tumors, exposures for cervical rhizotomy, tractotomy, and section of the ninth cranial nerve. Supratentorial lesions are operated upon in the supine position For frontoparietal exposures, the patient is placed supine with the head turned into position. For parietal exposures, the patient is placed in a position on his side, and with parietooccipital exposures the patient is placed prone and the head positioned to the desired place

With the upright position, frequent observations of the pulse and blood pressure are made. It is best to start an infusion of saline or a transfusion at the beginning of the operation A disadvantage of this position is the possibility of air embolism. In our experience this has caused no complications. The procedures described in this volume for the posterior fossa are all designed for the sitting position. DeMartel was an early champion of this position for many neurosurgical procedures He endeavored to "demonstrate since 1913 that the sitting position, when local anesthesia is used, is a good advance in neurological surgery"

## Surgical Facilities

The surgical techniques illustrated in the following pages rather obviously imply that complete neurosurgical equipment and instruments be available It is understood also that knowledge and experience in the use of such facilities must be well founded So important are the neurosurgical facilities to the operation that some analysis of their relationship is advisable. Although apparently minor factors are so often omitted in a dis-

cussion of surgical technique, details become links in a chain of circumstances which result in a good, fair or poor operation. The time at which the operation is done; the pressure of the schedule of the surgeon; his mood; the quality of the surgical nurses available; the make-up of the resident or intern assistants; the type of the patient operated upon; his preoperative preparation; these as well as many other more or less obvious influences determine the final result. The less obvious factors may be only mentioned. The more important ones deserve some description.

*Electrocautery.* Cautery for the control of hemorrhage has been used since ancient times. The application of an electrical current refined for aseptic and meticulous surgery of the brain was made by Cushing[30] in 1928. Use of the electrical current for cutting or coagulating tissue commonly employs a unit termed the "Bovie", named after W. T. Bovie.[30] This apparatus employs electrical circuits for the generation of high frequency current which may be used for the cutting of tissue or for the coagulation of vessels to arrest hemorrhage. The unit employs 110 volts, 60-cycle current, which in turn produces the same 110 volts, 60-cycle current. Thus, any type of operating table may be used without fear of electric shocks. This insulated current is then introduced into two independent types of circuits. One is employed for cutting tissue, the other for coagulation. The cutting current or cutting circuit is a so-called undamped type of current with an oscillating potential which remains constant. This type may be compared with a stream of water which is in a constant flow. The coagulating current, on the other hand, is a damped current, or has an oscillating potential which returns to zero. This type could be compared with a turning off and on of a faucet of water. Both of these types of circuits or currents may be controlled by means of adjustment of voltage delivered to the electrode which either cuts or coagulates.

So standardized is the place of electrocautery in neurosurgery, that no intracranial operation should be attempted without it. The value in hemostasis has been clearly established. Within a few moments, a bloody field may be transformed into a dry area by accurate searing of veins and arteries by coagulation current. The electrical current is applied to forceps, suction tip, ball tip, or other suitable conducting tools. The effectiveness of the cautery depends upon contact with the vessel in a dry field, thus suction is required to remove the blood, as contact is made between current and bleeding point. The suction tip may serve this dual purpose.

Although coagulation for hemostasis is the electrocautery's first use, simultaneous cutting and coagulation may also be employed. The latter requires a higher frequency current, productive also of greater damage to tissue in the area involved. Such a current may be applied to any cutting instrument or to a wire loop used for the purpose of cutting solid tumors. The cutting instrument is drawn slowly through the tissue, either brain or tumor, and vessels are thrombosed by burning. Larger vessels, particularly arteries, may escape coagulation. These require preparatory ligation by silk or hemostatic silver clips.

The disadvantage of electrocautery lies in the surrounding thermal damage to normal tissue, either directly or indirectly. The indirect radiation

of heat is considerable. Bailey[13] has noted changes at 1 cm. distance from an incision with the cutting current. Caution must be used in its employment about the cortex, brain stem, spinal cord, nerve roots, etc. Another disadvantage is the fact that unless properly used the coagulating or cutting current may initiate severe hemorrhage. For thin-walled vessels, it is important to make contact with the tissues before the initiation of the current. The possibility of necrosis of tissue in the vicinity of large vessels also deserves comment. In so far as possible, when in the vicinity of large blood vessels, such as the middle cerebral artery, electrocautery should be used at a minimum.

By close cooperation with the anesthetist the danger of an explosion may be avoided when an explosive anesthetic agent is used. The use of wet towels to separate the area of operation from the tubes carrying the anesthetic agent to the patient's trachea is worthwhile.

*Suction.* Krause[270] reported that he used suction as a new surgical aid in 1908. Originally, a rubber tube was used, the distal end being conical. The purpose of this suction apparatus was not aimed at sucking out the tumor, but to "accomplish its fixation on the surface (of the tumor) in such a manner that I am able to manipulate it and move it at will. The mass of the great majority of tumors is, as a rule, resistant enough and will not tear, from the suction it is subjected to." Krause pointed out that he had been told by Dr Schuster of Berlin that physiologists had long been accustomed to using pointed glass cannulae for the removal of very small bits of tissue from the cortical and subcortical regions. Physiologists used a water pump suction apparatus or an air pump driven by an electric motor. Krause reported that Perthes introduced the use of suction in surgery, using it in the postoperative treatment of empyema. Subsequently, Krause employed glass cylinders of various dimensions from 10 to 50 mm. After exposing the tumor as completely as possible a large fitting glass bell was applied to the surface and suction begun

A suction apparatus must be available for every neurosurgical operation. The suction power must be adequate (30 pounds of pressure) and continuous Small and large bore suction-tips, both straight and angled, are useful, depending upon the surgical field.

Besides clearing a field of blood preparatory to applying the electrocautery to a bayonet forceps, the suction tip may be used mechanically to compress a bleeding vessel, even large arteries and veins. Cautery may then be applied to the conducting suction tip A hemorrhaging middle meningeal artery, the internal carotid, or a large venous sinus, may thus be compressed and the bleeding controlled by cautery, a clip or packing. Suction is valuable in identifying an active bleeding source and drawing the vessel into the sucker's lumen for coagulation or for positioning it for clipping

The devitalized brain tissue of penetrating wounds produced by high velocity objects, such as shell fragments, may be debrided with the sucker. A core of tissue may be neatly excised Suction may be similarly applied to the removal of infiltrating brain tumors, using a larger bore tip Cysts may

be rapidly evacuated. Cavities containing spinal fluid and blood are also quickly aspirated of their contents. Subdural and epidural clots are evacuated by suction and irrigation. Excision of a lobe may be aided by the use of small bore suction which sections both by mechanical cleavage and suction, the latter identifying points of hemorrhage. Macerated brain tissue, following trauma, may be cautiously and advantageously removed by suction. Care must be used in avoiding trauma to normal structures, particularly surface vessels, which may be easily disrupted by an inadvertent grasp of this useful instrument.

*Silver Clips and Tantalum Clips.* The use of silver clips was suggested by Cushing[79] in 1911. McKenzie[101] modified the type and use of these clips. They are an important aid in hemostasis in some cases of intracranial bleeding. More recently tantalum clips have been used with comparable efficacy. Silver clips of different sizes are now used in order to obliterate larger abnormal vascular areas, such as portions of an aneurysm. The hemorrhage from a large artery or torn venous sinus may be immediately arrested by a well-placed silver clip, quickly taken from a clip holder, firmly grasped in a clip forceps and applied.

*Lighting.* Special lighting is an aid in neurosurgery since, in certain instances, lighting of a certain portion of the intracranial space is impossible with overhead or spot illumination. Under these circumstances a lighted retractor of the Frazier type suggested in 1928, may serve, or a headlight may be satisfactory. Cavity illumination with a Frazier retractor is preferable. Its usefulness is readily demonstrated in the subtemporal approach to the trigeminal nerve root and in tumors of the chiasm. Examination of cystic cavities for an intramural nodule can be accomplished by this close, direct lighting. Since the retractor set must be sterilized by immersion in a suitable antiseptic solution for thirty minutes, this instrument should be ordered as part of the surgical set to insure availability.

*Whole Blood.* Whole blood is recognized as often being the responsible factor in the success of a neurosurgical procedure. By its use surgical technique has been modified in several important ways. More radical procedures have been made possible, including particularly the attack upon vascular lesions of the brain. Bolder tumor extirpations are possible. A basic speeding up of the operation, with its completion in several hours, has replaced a system of time-consuming precision which protected the blood volume by a delay of many tedious hours at the operating table. Blood loss is replaced at will, under any circumstances and at any rate of flow. The formidable blood loss of an average craniotomy of 1000 to 1500 cc. is now usually replaced by the end of the operation. Transfusions are advisedly started at the beginning of the operation, particularly with patients in the upright position.

*Gelfoam®, Oxycel® and Muscle* Gelfoam® and oxycel® have been welcomed into neurosurgical practice after satisfactory trials. In many instances they have replaced the use of muscle grafts. These absorbable hemostatic agents are readily available in various textures of cotton or gauze of any size. Probably their best use is a temporary one, with removal after a hemo-

static purpose has been served. A quantity of such material filling a cavity is poorly absorbed even after months and acts as a foreign body. A small square of a single flap layer disintegrates in a much shorter period of time. In some instances the older method of muscle macerated between hemostats is superior. Particularly is this true in dealing with arteriovenous malformations.

*Bone Wax.* Bone wax also serves a specific and safe hemostatic purpose. This has been termed Horsley's[223] wax and consists of seven parts of bee's wax to one part each of almond oil and salicylic acid. It is applied easily when warm and then in a thin layer over bleeding bone areas. Whenever bone is removed in the skull, vascular channels may be encountered and troublesome oozing of blood occurs. This is best treated by the introduction of bone wax with sealing of the opening.

*The Finger Employed as an Instrument.* It is not at all unusual that there has been an unfavorable reaction to the use of the finger in neurologic surgery, since its improper use in the management of neurosurgical problems before the turn of the century was the cause of many fatalities. There are important uses however. The finger can apply bone wax; palpate bone edges; separate scalp from pericranium, identify the presence of a spinal cord tumor. The texture of peripheral nerves may be evaluated by a sense of touch and the presence of intraneural scar or neuroma may be detected in an otherwise normal appearing nerve. Palpation of the surface of the brain with the finger may give invaluable information by revealing the density of the subcortical tissue. The presence of a cyst, scar, or an infiltrating neoplasm may be suspected. A cannula then inserted into the area may transmit the "feel" of entering a cavity wall by the tensions of the tissues penetrated. This cavity may be a ventricle, wall of an abscess, hemorrhagic cyst, or neoplasm of varying density

The use of applying compression by the fingertips upon the scalp to reduce incisional bleeding before hemostats are applied is recognized. Occasionally a surface hemorrhage may require temporary gentle compression by the finger before a clip, coagulation or a hemostat is applied

Enucleation of a tumor with the help of a finger is undesirable except when the tumor is near the surface of the hemisphere. The manipulation has to be employed with caution and gentleness. After the surface of the mass is gently separated from the surrounding tissues, blood vessels are identified and clipped, or coagulated. The extent of the mass, its mobility and connections, may be recognized. The advisability of excision in part prior to mobilizing the mass may be then determined. Finger enucleation should never be attempted in deep-seated lesions about the optic chiasm or in the cerebellopontine angle. Gentle palpation of a penetrating wound tract reveals the presence of bone particles and foreign bodies, the removal of which is mandatory in the proper management of war wounds.

## Control of Hemorrhage

Since the control of hemorrhage in neurosurgical practice is a major problem, a more detailed consideration is presented Modern methods for

control of hemorrhage have provided a security which has made it possible for a more radical management of surgical lesions. As has already been mentioned, we have at our disposal various means and materials for hemostasis. These include the electrical coagulating current, cutting current, Cushing-MacKenzie clips, ligature, gelfoam® or fibrinfoam, cellulose gauze, crushed muscle, the suction tip combined with coagulating current. Throughout the text these methods of hemostasis are illustrated. Certain important sources of bleeding may be summarized.

*Scalp.* Bleeding from the scalp is controlled by finger pressure on the part of the operator and assistant along the line of the incision. The application of hemostats on the outer galea circumference and the use of Michel clips, large size, on the inner skin flap may then be used. Occasionally, larger vessels are encountered which may either be tied or cauterized with electrocautery. On the edge of the skin flap there may be active arterial bleeding. These are best treated by electrocautery. The bleeding point is held with a fine bayonet forceps, keeping the vessel under tension and away from the rest of the tissues. The cautery then burns only the bleeding point. This avoids an ulcerating scalp incision due to a burn. On the inner surface of the reflected scalp flap, there may be large bleeding points. These, also, should be individually grasped with a bayonet forceps and the tissues pulled away from the main mass of scalp flap while the cautery is applied.

*Bone.* The presence of diploic hemorrhage should be ascertained and such bleeding canals in the bone plugged with bone wax. The small bleeding areas on the internal surface of the bone flap may be treated either with bone wax, which is rubbed into the bleeding areas, or these bleeding points may be cauterized with a high cutting current at a setting of 60 to 70.

*Dura.* The dura presents meningeal vessels and these can be doubly ligated and cut, or the electrocautery may be used. The latter should be used sparingly, since retraction of the dura occurs on coagulation. This may make dural closure difficult. Troublesome hemorrhage may be encountered from the pacchionian granulations and venous tributaries of the sagittal sinus, as the dura is incised at or about the sagittal sinus. These are efficiently dealt with by small squares of gelfoam®, compressed under cottonoid. The gelfoam® is not removed. Dural bleeding is best controlled by making a free graft with resuturing The dural edge should be tented to the pericranium as illustrated in many of the accompanying figures to prevent a spreading epidural collection. Bleeding from the temporal muscle may be controlled by linear electrocoagulation of its base.

*Brain.* The brain bleeding is mainly dealt with by the electrocoagulating current, the use of silver clips and silk sutures. The electrocautery makes it possible for one to coagulate the surface vessels, which are grasped in a bayonet forceps first. One may also use a ball-tip electrode, placed in intimate contact with the vessels to be coagulated The vessels almost completely disappear under such form of hemostatic treatment. The current should not be turned on before the ball-tip has been placed upon the vessel.

The cutting current when used slowly aids in further control of bleeding, particularly from the deeper vessels. When employed too rapidly there is profuse bleeding from the deeper vessels not yet coagulated. When suction

is used upon the cerebral parenchyma the bleeding vessels reach the suction tip neighborhood, being pulled toward the tip of the suction tube. These vessels, along with their connective tissue, can be grasped and treated with a coagulating current. In the management of hemorrhage from the venous sinuses one is able to use silk ligatures. Before ligation it is necessary to incise the dura adequately about the sinus. When the sinus wall has been torn it is not desirable to ligate the sinus. The method of tamponade by means of muscle or gelfoam® held against the opening in the sinus by two or three sutures passed through the dura from the one side of the tear to the other side, is practical. In some instances, it is possible to repair the tear in the sinus with interrupted or continuous fine silk sutures. Following completion of the suturing a piece of gelfoam® or muscle may be applied.

In the management of cerebral aneurysms, if the arteriovenous lesion on the convexity of the brain is fairly discrete, excision of the entire area, beginning in normal-appearing brain tissue, is simpler than attacking the aneurysm itself. The larger vessels extending toward the aneurysmal area may be coagulated or ligated and cut. These lesions, at times, call for all forms of hemostatic agents. It is important to have these readily available. Muscle stamps may be superior to gelfoam® in certain situations.

The common and internal carotid arteries may be exposed in the neck for the purpose of aiding in the hemostasis by ligating or compressing the vessels in the neck. For aneurysms at the base of the brain it is possible in some instances to ligate the neck of the saccular aneurysm. In some cases, the aneurysm wall ruptures. With good suction, under clear vision, the aneurysmal sac is usually packed with muscle or gelfoam®.

In instances where a lobectomy has been performed, a thin layer of cellulose gauze is efficient in covering over the raw surface of the brain. The tumor bed is usually lined with gelfoam® or cellulose gauze for better hemostasis. In so far as possible all excess hemostatic material should be removed.

## Preoperative and Postoperative Care

*Preoperative.* Ideal preoperative care presupposes that the patient reaches the operating room as a satisfactory surgical risk. The basis for this condition is correctness of the preoperative diagnosis An opportunity for gaining all additional information is present in the preoperative period. The plan of surgical management may then be executed with a minimum of fortuitous events. Not only must surgical findings be anticipated but the patient must be viewed preoperatively as a whole organism rather than having an isolated neurological lesion. The patient with a ruptured disc may be a psychiatric problem; the head injury patient may present a pneumothorax, the brain tumor may be of metastatic origin. Unless all systems have been considered and investigated the preoperative care is incomplete

The immediate preparation for surgery has been stripped to simple essentials. The most important of these is a visit by the anesthetist who, like the neurosurgeon, gains complete information concerning those systems within his sphere The availability of blood, the preparation of essential

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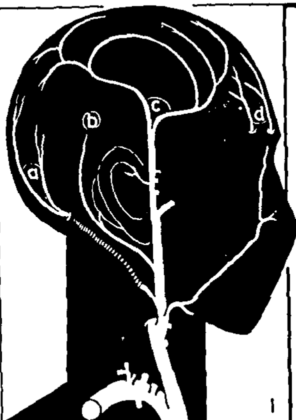
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In *2* is a diagrammatic representation of communications between the external carotid, the internal carotid, and the vertebral arteries. The external maxillary shown at *b* communicates with branches of the supra-orbital and frontal shown at *c*. Thus, a communication is established between branches of the internal and external carotid at this point. The descending branch of the occipital at *a* communicates with the deep cervical, which in turn sends anastomotic branches to the vertebral, thus establishing a circuit for the vertebral system. The costocervical, a branch of which is the deep cervical artery, is seen at *f*.

In *3* the meningeal arteries supplying the dura are diagrammatically represented. In the posterior fossa *a* there are meningeal vessels to the dura from the occipital, the vertebral, and the ascending pharyngeal branch of the external carotid artery. In the middle fossa *b* the middle meningeal and the accessory meningeal branches of the internal maxillary are the main supply. Also included are branches from the internal carotid. The anterior fossa dural lining is supplied by a meningeal branch of the internal carotid artery and meningeal branches of the anterior and posterior ethmoid arteries *c*.

In *4* the arterial branches from the aortic arch are shown and they are the right innominate artery, dividing into the subclavian, and the common carotid, *b* is the left subclavian and *c* is the left common carotid. The internal maxillary branch of the external carotid is shown at *d* and the important branches of the internal maxillary include the middle and accessory meningeal and the inferior alveolar shown at *e*, the deep temporal and other vascular branches at *f*, the posterior-superior alveolar at *g*, at *h* the sphenopalatine, the pharyngeal and descending palatine arteries and the infra-orbital branches.

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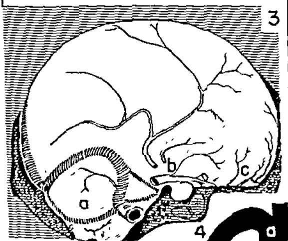



1. Arterial Supply of Scalp.
   a. Occipital artery.
   b. Posterior auricular.
   c. Superficial temporal.
   d. Frontal and supra-orbital.

2. Extra- and intracranial arterial anastomosis.
   a. Occipital, ascending and descending branches
   b. External maxillary
   c. Frontal and supra-orbital.
   d. Circle of Willis.
   e. Vertebral and basilar.
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   b. Middle meningeal and accessory meningeal and branch of internal carotid for the middle fossa.
   c. Anterior meningeal branch of anterior and posterior ethmoidal arteries for the anterior fossa.




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   b. Left subclavian
   c. Left common carotid
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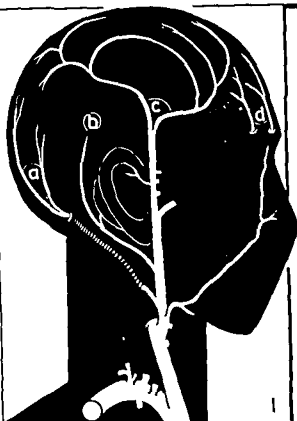
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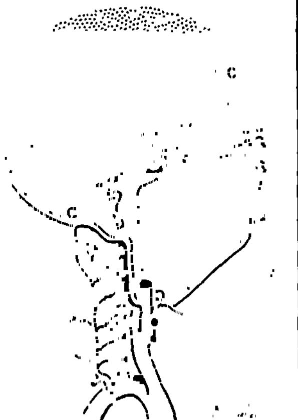
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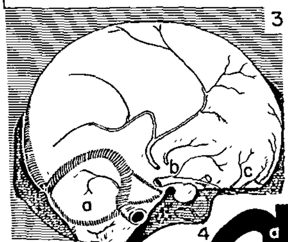


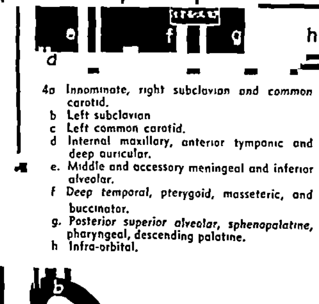

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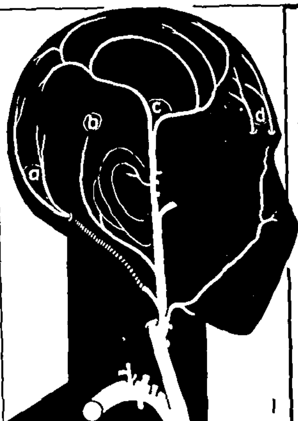
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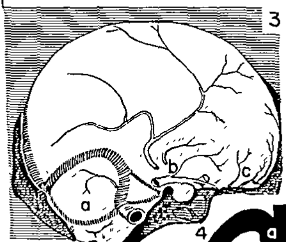



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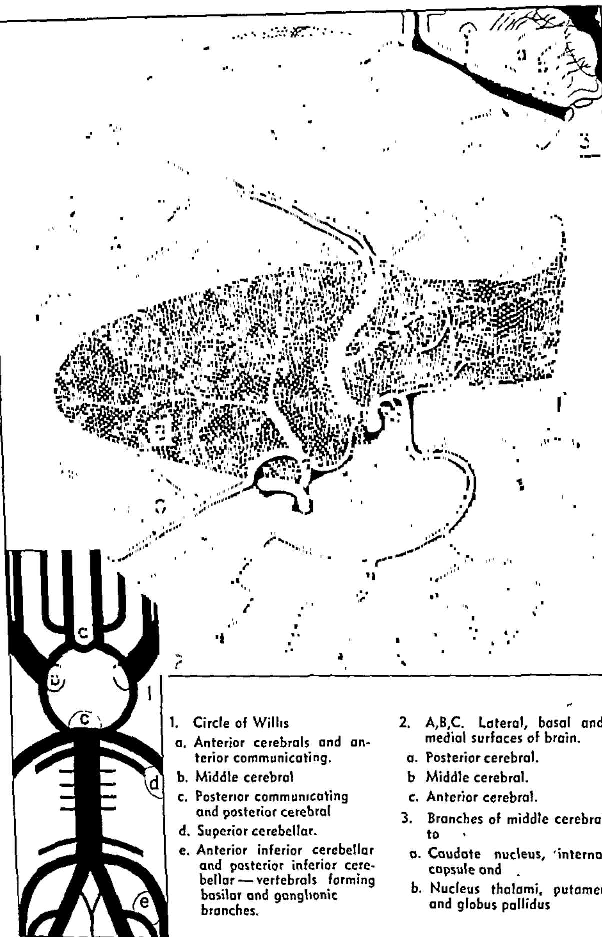


In *1* the schematic representation of the circle of Willis and the various branches of the same are shown. At *b* one sees the middle cerebral which is a continuation of the internal carotid artery. At *a* is shown the anterior communicating and the two anterior cerebral arteries. Posterior to *b* is the posterior communicating and at *c* is the junction of the posterior cerebral with the posterior communicating. The posterior cerebral is given off from the cephalic end of the basilar artery. Just a little caudad to the posterior cerebral is the superior cerebellar shown at *d*. Many ganglionic branches are given off from the basilar. A rather large one is the internal auditory artery which is shown just above the formation of the basilar by the confluence of the two vertebral arteries. At *e* above and arising from the basilar is the anterior-inferior cerebellar artery and below, arising from the vertebral, is the posterior-inferior cerebellar artery. The two vertebrals give rise to the anterior spinal by the union of a small branch from each.

A composite representation of the blood supply of the brain is seen in *2* from the lateral aspect, the base and medial aspect of the hemisphere. At *a* one sees the posterior cerebral given off from the basilar with the posterior communicating extending toward *b*. The posterior cerebral supplies mainly the base and the medial aspect of the temporal and occipital portions of the brain. Its branches include the temporal branches, the parieto-occipital branch, and the calcarine branch. The posterior cerebral artery winds around the cerebral peduncle and reaches the tentorial surface of the occipital lobe of the cerebrum, and then it breaks into branches which supply this neighborhood. A group of small arteries arising from the posterior cerebral near its origin supply the posterior portions of the thalamus and the wall of the third ventricle, as well as the choroid plexus. The temporal branches are distributed to the uncus and the anterior part of the fusiform gyrus as well as the inferior temporal gyri The calcarine branch supplies the cuneus and lingual gyrus and the posterior aspect of the convex surface of the occipital lobe The parieto-occipital branch supplies the cuneus and precuneus.

Between *a* and *b* is the posterior communicating which connects the internal carotid with the posterior cerebral artery. At *b* is the continuation of the internal carotid in the form of middle cerebral artery. The branches of the middle cerebral include the inferior lateral frontal, the ascending frontal, the ascending parietal, the parietotemporal and the temporal branches. The artery extends up in the Sylvian fissure, it gives off many small twigs to the basal nuclei, the caudate nucleus, the globus pallidus, the internal capsule, the putamen and the thalamus

At *c* is the anterior cerebral with the anterior communicating shown. The anterior cerebral passes forward and medially across the anterior perforated substance above the optic nerve. Reaching the longitudinal fissure it accompanies the opposite anterior cerebral and is connected with same through the anterior communicating artery. The anterior cerebral




1. Circle of Willis
   a. Anterior cerebrals and anterior communicating.
   b. Middle cerebral
   c. Posterior communicating and posterior cerebral
   d. Superior cerebellar.
   e. Anterior inferior cerebellar and posterior inferior cerebellar — vertebrals forming basilar and ganglionic branches.

2. A,B,C. Lateral, basal and medial surfaces of brain.
   a. Posterior cerebral.
   b. Middle cerebral.
   c. Anterior cerebral.

3. Branches of middle cerebral to
   a. Caudate nucleus, internal capsule and
   b. Nucleus thalami, putamen and globus pallidus

courses around the genu of the corpus callosum; and extends backward, on the upper surface of this structure, extending all the way to the posterior part of the corpus callosum. Its branches include the anterior medial frontal (frontopolar), intermediate medial frontal (callosomarginal) and the posterior medial frontal (pericallosal), as well as the orbital branch which supplies the more forward portions of the frontal lobe.

In *3* branches from the middle cerebral to the caudate putamen, globus pallidus, internal capsule and thalamus are shown diagrammatically.

## Venous drainage of the intracranial structures.

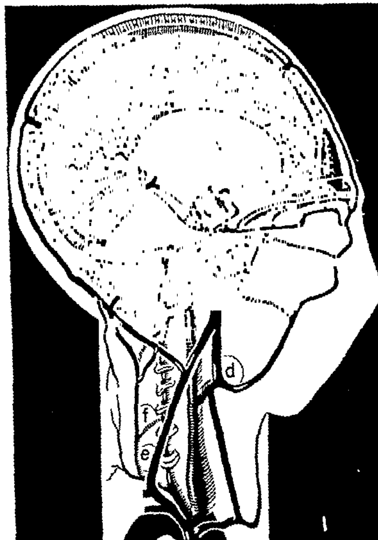
## *Cross section of the scalp*



The venous drainage of the cranial and intracranial structures is shown in *1*, *2*, *3* and *4*. In *1*, *a* represents the superior sagittal sinus with emissary veins communicating with scalp veins. The great vein of Galen is shown at *b* entering the junction of the inferior sagittal and straight sinuses. The great vein of Galen consists of the union of the two internal cerebral veins draining the deeper parts of the hemisphere, including the thalamus, the striate bodies, the corpus callosum and the choroid plexus. The confluence of sinuses is seen when the superior and straight sinuses are followed to the lateral sinus. Each lateral sinus becomes continuous with the internal jugular vein. At *c* one sees the cavernous sinus which communicates with its fellow on the opposite side and receives drainage from the orbital structures and also communicates with the superior petrosal and inferior petrosal sinuses and the pterygoid plexus. The cavernous sinus also communicates with the basilar plexus which is on the basilar process of the occipital bone.

The cerebral veins are divided into the external and internal group. Those making up the great vein of Galen belong to the internal group, whereas the external group consists of the superior, inferior and middle cerebral veins. The superior cerebral veins are eight or ten in number and they empty into the sagittal sinus, running across the superior and lateral aspects of the hemisphere. The anterior veins run nearly at right angles, whereas the more posterior and larger veins are directed obliquely forward and medially. The middle cerebral vein is the large venous channel in the Sylvian fissure and ends in the cavernous sinus The inferior cerebral veins drain the undersurfaces of the hemisphere and join the cavernous, the sphenoparietal and superior petrosal sinuses. On exposure of the middle and anterior fossae, some of these veins may be seen to cross from the surface of the hemisphere into a given sinus and may cause tremendous bleeding if not recognized and dealt with properly. Finally, there are anastomotic veins between the sagittal sinus and the middle cerebral vein and the lateral sinus The great anastomotic vein of Trolard connects the middle cerebral vein with the superior sagittal sinus and the posterior anastomotic vein of Labbé is the communication between the transverse sinus and the middle cerebral vein.

In *2* one sees arachnoid granulations at *a* on either side of the sagittal




Venous drainage and skin.

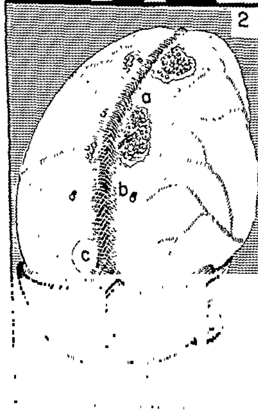
1a. Superior sagittal sinus and emissary veins.
b. Vein of Galen, inferior sagittal and straight sinuses.
c. Cavernous sinus, ophthalmic vein and pterygoid plexus.
d. Facial and anterior jugular.
e. External jugular.
f. Descending occipital, deep cervical and vertebral.

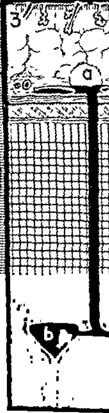
2a. Superior sagittal sinus and arachnoid granulations.
b. Parietal emissary veins.
c. Confluence of sinuses.

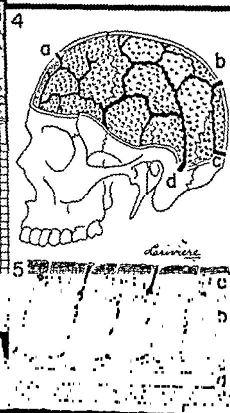
3. Section of scalp, skull and dura.
a. Emissary vein.
b. Sagittal sinus and arachnoid villus.

4. Diploic and a,b,c,d. Frontal, parietal, occipital and mastoid emissary veins.

5. Scalp.
a. Cutis.
b. Subcutis.
c. Superficial fascia
d. Galea.
e. Subgaleal space.
f. Pericranium.



sinus. Emissary veins are represented at *b*. The confluence of sinuses with the occipital sinus extending down and the lateral sinuses extending into the jugular veins are shown at *c*.

In *3* a section of the scalp, skull, brain and membranes is shown. At *a* is an emissary vein. Cross section of the superior sagittal sinus at *b* shows arachnoid granulations extending into the sinus cavity. Between *a* and *b* is the cranial bone.

In *4* are shown the venous channels in the diploe and they are roughly grouped into a frontal, anterior temporal, posterior temporal and occipital tributaries. Many connections with veins on the outside of the skull are noted, such as one in the frontal area at *a*, one in the posterior parietal area at *b*, one in the occipital region at *c* and another in the mastoid area at *d*, are emissary communications.

In *5* a cross section of the scalp is shown, with *a* showing cutis, *b* subcutis, *c* the superficial fascia, *d* the galea aponeurotica, *e* the subgaleal space and finally, *f* the pericranium.

**Cerebral topography after Brodmann**

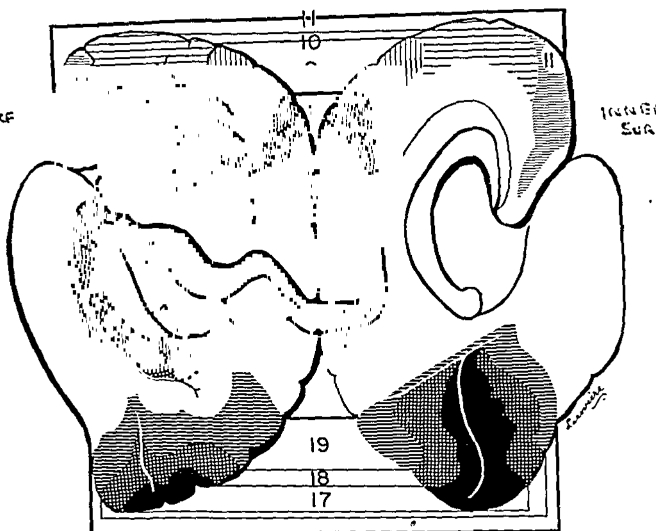


## Pathologic Physiology

## of the Cerebral Hemispheres

The cerebral hemisphere is roughly divided into four lobes by the presence of three main fissures which are the Sylvian fissure, the central sulcus, and the parieto-occipital fissure The frontal lobe is that portion of the brain which is anterior to the central sulcus and superior to the Sylvian fissure. The temporal lobe is below the Sylvian fissure and extends all the way back to the angular gyrus and the lateral occipital sulcus. The parietal lobe is bounded anteriorly by the central sulcus and posteriorly by the parieto-occipital fissure and the lateral occipital sulcus. The occipital lobe is posterior to the parietooccipital fissure.

*Frontal Lobe.* The posterior boundary of the frontal lobe is the central sulcus, anterior to which is the motor area of the brain or the precentral gyrus This is the area 4 of Brodmann's terminology. Immediately anterior to this area is area 6, which consists of the posterior portions of the superior and middle frontal convolutions These areas also include suppressor strips, the stimulation of which experimentally results in suppression of a motor action. Still more anteriorly, as shown in the accompanying figure, is the area 8 These three areas are intimately associated with the motor function of the body. The involvement of the area 4, without associated involvement of the area 6, results in a flaccid paralysis of the opposite half of the body. When both area 4 and area 6 are involved, which is usually the case, then a spastic paralysis of the opposite half of the body is obtained. Depending upon the extent of the cortical involvement, there may be a motor deficit in the opposite half of the body involving the face and arm regions or the lower extremity. The lower extremity centers are on the uppermost portion of the precentral gyrus, but primarily on the medial surface of the




| | |
|---|---|
| Areas 3-1-2 | Post central sensory area. |
| Area 4 | Motor area. |
| Area 6 | Premotor cortex. |
| Area 8 | Frontal eye field. |
| Areas 9-10-11 | Prefrontal cortex. |
| Area 17 | Visual cortex. |
| Areas 18-19 | Visual correlation cortex. |
| Area 41 | Primary auditory cortex. |
| Areas 22-42 | Acoustic correlation cortex. |
| Area 43 | Swallowing center. |
| Area 44 | Broca's area. |
| Areas 45-46 | Inferior frontal convolution. |

hemisphere adjacent to this region. Involvement in this area by a parasagittal meningioma may result in a lower extremity deficit on the opposite side of the body. A midline tumor compressing both lower extremity centers and the paracentral lobule may result in paraplegia with associated sphincter paralysis, simulating a spinal cord lesion.

In a sufficiently extensive lesion, the entire motor area may be involved resulting in a hemiplegia of the opposite half of the body, characterized by weakness of the lower half of the face and paralysis of the upper and lower limbs. In the majority of the cases, as the patient continues in this state, the paralysis of the upper extremity is much more severe than that in the lower extremity. This may be partly due to the fact that the lower extremity function is mediated by both motor cortices. Particularly is this true of the more proximal portion of the lower extremity. Consequently, it is possible for the patient to carry on with a hemiplegic gait and utilize the lower extremity to a greater advantage than the upper extremity. The latter is much more severely involved. The extremity is resistant to passive movement, with sudden subsidence of the resistance as seen in the so-called lengthening reaction. There is adduction and internal rotation at the shoulder and flexion at the elbow. The forearm is pronated and there is flexion of the fingers. It should be noted that involvement of area 4 primarily would result in flaccidity of the opposite half of the body, with a Babinski sign; whereas, involvement of area 6 of Brodmann primarily results in spasticity of the opposite half of the body without loss of power, but with impairment of skilled movements and vasomotor changes in the affected side. Where both 4 and 6 are involved, the spasticity is much greater.

Irritation of the precentral gyrus region may result in convulsive seizures of the Jacksonian type. These attacks usually begin in a certain part of the body and from there, may extend to the remaining portion. In a severe attack there may be generalized convulsive involvement with unconsciousness. Immediately following such an attack there may be a weakness or paralysis of the most affected part. This is usually transitory and is spoken of as Todd's paralysis. Its presence is of significant localizing value.

Disturbances of speech result from involvement of the posterior inferior frontal convolution or the region of the Broca's convolution on the left side in the right handed individual. The motor or expressive type of aphasia usually results from an involvement of the frontal portion of the aphasia area; whereas, the sensory aphasias result from an involvement of the posterior superior temporal gyrus Inability to name objects or anomia is frequently seen with temporal lobe lesions.

The portion of the frontal lobe anterior to the areas 4, 6 and 8, or the frontal lobe proper mediates the high psychic functions. A disturbance of this region results in peculiarities of behavior, lack of interest, loss of the normal emotional stability, untidiness, speech may become obscene and behavior antisocial. Memory is definitely impaired, particularly for recent events

Among other physical signs of frontal lobe involvement may be included forced grasping and groping Such an occurrence in one half of the body

may be of localizing significance and implicates the area 6 of Brodmann. It should be pointed out, however, that if the condition occurs in both upper limbs, it may be the result of generalized increased intracranial pressure and consequently is not of value in lateralization.

*Parietal Lobe.* The parietal lobe includes the sensory area, areas 1, 2 and 3, according to Brodmann, lying in the postcentral gyrus, a portion of Broca's neighborhood posterior to the central sulcus near the temporal lobe, the angular gyrus and the paracentral lobule on the medial surface of the hemisphere. Dysfunction of this area results in sensory changes of cortical origin. Localization of sensation, sense of motion and position, and stereognostic sense are mediated through this portion of the cortex. Although modalities such as touch, temperature and pain are perceived with lesions involving this area, yet the threshold of perception is much higher than on the normal side. At times, there may be an alteration in the perception of the modality, so that a stimulus which is ordinarily bearable may be quite unpleasant. There may be sensory Jacksonian fits, with irritation of the postcentral gyrus neighborhood. However, in most cases, it is difficult to evaluate such sensory fits, unless associated with motor manifestations of either Jacksonian or generalized character following the sensory disturbance. Deep lesions of the parietal lobe produce homonymous defects in the visual fields, and since there is almost always an involvement of the adjacent motor cortex, there is also an associated hemiparesis or hemiplegia of the opposite half of the body. Involvement of the parietal lobe inferiorly and anteriorly on the left side results in a sensory type of aphasia; whereas, involvement of the angular neighborhood results in agraphia and alexia.

*Temporal Lobe* Disturbances from involvement of the temporal lobe include visual field defects and uncinate fits. There may be visual hallucinations. These are usually of formed objects; whereas, hallucinations from an occipital lobe involvement are said to be flashes of light and varying colors. On the left side, there may also be aphasic disturbances. In the beginning these may be mainly of the sensory type of aphasia Visual field defects in temporal lobe disease are of the homonymous type and usually involve the upper quadrants first, eventuating in complete hemianopia. Uncinate fits, also described as dreamy states, may be initiated with bad odors With the onset of the peculiar odor, the patient, becomes semiconscious and loses touch with his environment. There may be smacking of the lips. There may be associated visual hallucinations. At times, the whole picture may be followed by generalized convulsions. Extension of the involvement toward the frontal lobe may result in associated weakness of the face and eventually increasing motor deficit in the opposite half of the body, beginning with the upper extremity.

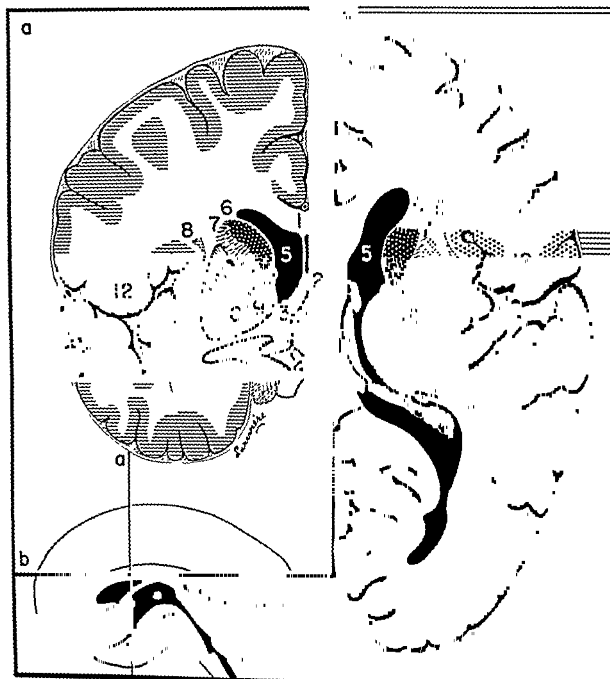
Uncal herniation into the incisura may compress the brain stem in such a manner that the opposite side is pressed against the border of the tentorium Under such circumstances, weakness or paralysis may occur on the same side as the lesion. Such false localizing signs are seen with massive lesions such as epidural and subdural hematomas.

Deep in the temporal lobe and forming the floor of the island of Reil are the Heschl's convolutions, representing area 41 of Brodmann, which are the sensory receptive centers for auditory impulses. Areas 42 and 22 in immediate juxtaposition in the superior temporal convolution are the correlation centers for auditory impulses. Since auditory impulses are passed on to both hemispheres, an involvement of one temporal lobe is not associated with auditory difficulties. The decussation of these auditory fibers, of course, occurs in the pons.

*Occipital Lobe.* Dysfunction of the occipital lobe is associated with homonymous hemianopia. It is stated that in occipital lobe involvement there is sparing of the macular vision; if there is a lesion of the optic radiations anteriorly, such as in the temporal lobe, the macula is not spared. However, in occipital lobe lesions, macular involvement is also present in many cases, so that on visual field studies alone an accurate localization is not possible. Visual hallucinations, when they occur, due to occipital lobe lesions, are said to be flashes of light, instead of the formed figures of temporal lobe etiology. Such hallucinations may be followed by generalized convulsive seizures. On the left side, occipital lobe involvement may result in visual agnosia; further forward, there may be an inability to recognize the opposite half of the body, as described by Gerstmann and Neilson. Area 17, the cortex of the posterior portion of the calcarine fissure is the primary visual center, while the adjoining areas 18 and 19 are the correlation centers for visual impulses. The visual cortex is typified by the presence of the stria of Gennari; this may be seen grossly. It is made up of a band of nerve fibers, the outer band of Baillarger.

*Thalamus.* Lesions of a progressive nature in the thalamus may result in the so-called thalamic syndrome which is characterized by sensory phenomena in the opposite half of the body which is not complete in most cases. Sense of position, sense of pressure, vibratory sense are more involved than the superficial forms of sensation such as light touch, pain and temperature. There may be pain in the hypesthetic and anesthetic areas of the body. At times, this has given rise to false diagnoses, such as appendicitis, with right lower quadrant pain of thalamic origin, gallbladder disease, with upper quadrant pain on the right side of thalamic origin, shoulder pains of thalamic origin. There may be a mild hemiplegia on the opposite side, and in some cases, choreo-athetoid movements of the opposite half of the body may be noted. With extensive involvement, there may be a contralateral homonymous hemianopsia.

*Midbrain* involvement is usually characterized by abnormality of conjugate movements of the eyes. Paralysis of upward gaze and convergence are the most common, with involvement of the dorsal portions of the midbrain. When the more anterior portions of the midbrain are involved, there may be third nerve paralysis on the side of the lesion with paralysis of the opposite side of the body (Weber's syndrome). Benedikt's syndrome is associated with a third nerve paralysis on the same and hemi-anesthesia and tremors in the opposite half of the body. These tremors are due to an involvement of the red nucleus and they are much more severe at the end of a movement—terminal tremors.




a Cross section of brain.

b. Horizontal section of brain, levels indicated in the outline in lower left corner.

1. Corpus callosum.
2. Fornix
3. Anterior commissure.
4. Optic chiasm.
5 Lateral ventricle.
6. Head and tail of caudate nucleus
7. Internal capsule.
8. Claustrum.
9, 10. Globus pallidus.
11. Putamen.
12 Island of Reil.
13. Thalamus.
14. Hippocampus.
15. Optic radiation.

*Third ventricle* lesions may be associated with signs of increased intracranial pressure, as well as with signs due to involvement of the floor of the third ventricle. The so-called ball-valve action of a third ventricle pedunculated tumor may explain attacks of severe disability followed by return to normal. The tumor may obstruct the flow of cerebrospinal fluid and give rise to an attack of increased intracranial pressure with associated somnolence, and convulsive seizures. Then suddenly, possibly due to a movement of the head, the obstruction is relieved, and there is return to normal. Some tumors of the third ventricle arise from neighborhood structures, such as pituitary tumors, craniopharyngiomas and tumors from the wall of the third ventricle, invading this neighborhood secondarily. In many of these patients, the manifestations include evidences of water imbalance characterized by diabetes insipidus, temperature imbalance, imbalance of fat metabolism, associated with the so-called adiposogenital dystrophy, somnolence, with the patient falling asleep from which he may be awakened with ease. Some patients may have diencephalic autonomic seizures, associated with marked sweating, lacrimation, salivation, increased pulse rate and slowing respirations, rise in blood pressure, and occasionally, marked emotional difficulties, such as rage and severe excitability. Gastrointestinal ulcerations due to central nervous system disease usually are mediated through the hypothalamico-sympathetic connections. Certain frontal lobe and third ventricle tumors may thus be associated with gastric ulcerations.

*Pineal* lesions usually produce involvement of the posterior midbrain, associated with inability to gaze upward and in some instances, inability to converge the eyeballs. In young children, there may be precocious puberty, but this is not necessarily due to a tumor of this region. Hypothalamic tumors may also result in such a manifestation.

Dorsal *pontine* lesions may be associated with involvement of conjugate movements of the eyes With a lesion of the more anterior portions of the pons, cranial nerves may be implicated with contralateral paralysis or paresis of the body due to pressure or destruction of the pyramidal tract. Thus there may be seventh nerve paralysis on the side of the lesion, with paralysis of the opposite half of the body. Lower down in the medulla, the ninth, the tenth and the twelfth cranial nerves may be involved, with difficulty in swallowing and paralysis of the vocal cord on the affected side with hoarseness. Almost always there is associated involvement of the cerebellar peduncles with marked ataxia on the side of the lesion Pyramidal tract involvement results in a crossed paralysis.

*Cerebellum.* Dysfunction of the cerebellum depends upon which portion of the cerebellar structure has been implicated. The flocculonodular lobe, the oldest part of the cerebellum, is connected with the vestibular centers of the brain stem Its involvement by medulloblastoma results in trunk ataxia, without nystagmus or other cerebellar signs. The anterior cerebellar lobe, which is that portion of the cerebellar lobe in front of the primary fissure, may give rise to cerebellar fits when involved by a tumor. These

fits are characterized by a sudden retraction of the head, arching of the back and extremities. There may be interference with respirations, and such attacks at times may terminate fatally. The posterior lobe of the cerebellum, or that portion of the cerebellum posterior to the primary fissure, not including the flocculonodular lobe, is the most recent portion of the cerebellum and is connected with the pons through the middle cerebellar peduncle. The symptoms of a lesion of the posterior cerebellar lobe include adiadochokinesis, dysmetria, a tendency to fall to the side of the lesion, weakness of the affected half of the body, which is on the same side as the lesion in the cerebellum, and loss or diminution of tendon reflexes on the affected side. The patient almost always displays a nystagmus, with a slower and coarser component on looking toward the side of the lesion and faster movements on looking away from the lesion.

Whereas, tumors of the pons and the medulla cause increased intracranial pressure very late, tumors of the cerebellum are associated with increased intracranial pressure earlier than neoplasms in most other locations. Headaches, vomiting and visual disturbances are common. Rigidity of the neck may occur with a tendency for the head to be flexed with the occiput toward the side of the lesion. Cerebellar tumors may involve neighboring structures, such as the cranial nerves and the brain stem. Paralysis of the lateral rectus may occur, and if seen, is of no localizing value. It may be on the same side or the opposite side as the lesion.

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### *Ventricular System of Cavities*

The ventricular system of cavities includes paired lateral ventricles and unpaired third and fourth ventricles. The lateral ventricle consists of an anterior horn, posterior horn, inferior horn and body. It communicates with the third ventricle through the foramen of Monro. It contains the choroid plexus which extends from the foramen of Monro all the way down to the tip of the inferior horn. The third ventricle is a flattened, slit-like space between the two hemispheres, dividing the thalamus, subthalamus, and the hypothalmus. It communicates anteriorly and superiorly with the foramen of Monro and anteriorly and inferiorly it has a rather acute extension which is called the optic recess, immediately posterior to which is another extension about the infundibulum or the infundibular recess. Posteriorly, the third ventricle has a suprapineal recess Posteriorly and inferiorly, it communicates with the fourth ventricle through the aqueduct of Sylvius. The fourth ventricle is a grossly quadrangular space which communicates with the subarachnoid space of the posterior fossa through the foramen of Magendie which is single and the foramina of Luschka, a pair of openings arising from the lateral recess of the fourth ventricle.

The lateral ventricle is bounded by the corpus callosum superiorly, the septum pellucidum medially and the head of the caudate, the thalamus,

and the lateral and posterior portions of the fornix inferiorly and laterally. The medial wall of the posterior horn presents an indentation caused by the calcarine fissure which is technically called the calcar avis or hippocampus minor. The bulb of the posterior cornu is made up of callosal fibers sweeping around to enter the occipital lobe. It is a slight projection immediately above the calcar avis. The inferior horn of the lateral ventricle is housed in the temporal lobe of the brain and curves around the posterior aspect of the thalamus. It extends to within 1 inch of the temporal lobe tip. The superior wall of the temporal horn is made up of callosal fibers, the tail of the caudate nucleus and the stria terminalis. The floor is made up of the hippocampal gyrus.

*Formation of Cerebrospinal Fluid*

Cerebrospinal fluid is formed mainly by the choroid plexus of the lateral, third and fourth ventricles. It is a dialysate. It is said that the capillary blood pressure is usually higher than the cerebrospinal fluid pressure. The latter pressure, in turn, is somewhat higher than the venous pressure in the large sinuses of the dura. The cerebrospinal fluid, therefore, dialyzes from the choroid plexus capillaries into the ventricles, and may be absorbed into the venous flow of the dural sinuses through the arachnoid villi. Part of the fluid also may escape into the lymphatic vessels through perineural lymphatic channels. Although not well proven, another supply of cerebrospinal fluid may be possible through its elaboration in the perivascular spaces of the cerebral blood vessels.

The cerebrospinal fluid is a limpid clear fluid and in the adult there may be a total of 100 to 150 cc. of this fluid in the ventricular and subarachnoid cavities. Of this amount, about 45 to 50 cc. is found in the ventricular cavities and the remainder in the subarachnoid spaces. The specific gravity of the fluid normally is 1.006 to 1.009 when obtained by a spinal puncture. The ventricular spinal fluid has a lower specific gravity (1.002 to 1.004). The total protein is under 35 mg. per cent and this is somewhat lower when the fluid is obtained from the ventricles. Glucose content of the cerebrospinal fluid is from $\frac{1}{2}$ to $\frac{2}{3}$ of the glucose content of the blood. Chlorides vary from 700 to 750 mg. per cent. The calcium content of the cerebrospinal fluid averages between 4.5 to 5.5 mg. per 100 cc.; organic phosphorus 1.25 to 2.1 mg. per cent; potassium, from 11 to 20 mg. per cent, magnesium 2 to $3\frac{1}{2}$ mg. per cent, lactic acid, 9 to 25 mg. per cent, nonprotein nitrogen, 10 mg. per cent; nitrogen 10 to 25 mg. per cent; creatinine 1.2 mg. per cent; uric acid 0.7 mg. per cent, carbonate content of cerebrospinal fluid averages 21 milliequivalents per liter (DeJong). The spinal fluid contains less than five cells normally and the serologic examinations are negative in the normal case.

# Supratentorial and Vascular Lesions

## Ventricular Puncture, Ventricular Estimation and Ventriculography

THE USE of air substituted for cerebrospinal fluid in the cerebral ventricles was employed first by Dandy[4,5] in 1918 as a diagnostic procedure. Injection was made by means of openings in the skull or through the intact fontanel of infants and roentgen examination made. The result of this procedure was termed a ventriculogram. The direct injection of air into the ventricles was then followed by the employment of a lumbar puncture with air injection into the lumbar sac with the patient in the upright position. Bingel termed the latter procedure pneumoencephalography or encephalography. As originally suggested by Dandy, a ventriculogram was performed by burr openings made in the occipital bone 3 cm. superior to the inion and 2 cm. from the midline. Frontal openings were also used and these were made 3 cm. posterior to a normal hairline and 2½ cm. from the midline. A modification of the ventriculogram, also suggested by Dandy, was the use of a ventricular estimation. The contents of each ventricle were measured after aspiration and a disparity in the contents indicated a mass present within the hemisphere of the smaller ventricle.

It was recommended also that a suitable test for communication between the ventricles or between the ventricles and spinal subarachnoid space could be proved by the means of the instillation of 1 cc. of indigo carmine dye. Recovery of the dye in the opposite ventricle or by lumbar puncture in the subarachnoid space would indicate communication.

Since the introduction of air, various other media have been employed in visualizing the ventricular system. These include carbon dioxide as recommended by Bingel in 1922. Oxygen, nitrous oxide and helium have also been employed Liquid media have also been used including lipiodol®, thorotrast®, and diodrast® and pantopaque® The use of air, however, has remained the medium of choice.

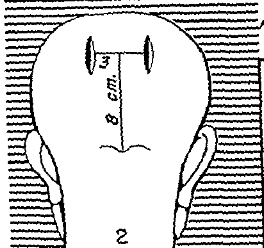
In *1* the position of the ventricle in relation to the usual openings made for ventricular puncture is shown. At *a* the needle has entered the ventricle through a trephine opening in the posteroparietal area about 1½ inches above and behind the ear. At *b* the ventricle is entered through an occipital opening 3 cm. from the midline and 6 or 8 cm. above the external occipital protuberance. At *c* the frontal portion of the lateral ventricle is entered through a trephine opening at the parietofrontal junction, 3 cm. from the midline.

The direction of the needle is as follows: At *a* the needle is introduced in a direction somewhat forward and upward in a line from the plane of the posterior aspect of the right ear to the plane of the anterior aspect of the left ear. At *b* the needle is introduced in a line extending to the tip of the top of the ear and toward the center of the eye on the same side. At *c* the needle is introduced downward and somewhat posteriorly. When the needle enters the ventricular cavity a change in resistance is noted.

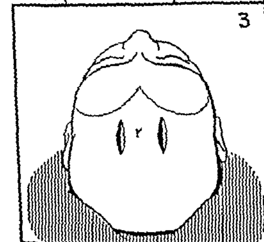
In *2* the position of the two incisions for the trephine openings, preparatory to ventriculography, is shown. The patient is in a sitting position with the head slightly forward. The incision is made 3 cm. on either side of the midline at a point 8 cm. superior to the external occipital protuberance.

In *3* the incisions are made in the frontoparietal area on either side of the midline overlying the frontal pole of the ventricle. Such openings are also used in exploration for a subdural hematoma or frontal lobe tumor. Such an incision and opening allows inspection of the surface of the frontal lobe followed by ventriculography if necessary.

In *4* the incision for a puncture of the body of the ventricle is shown about 1½ inches above and behind the ear.




1. Various approaches to lateral ventricle *a, b, c*.
2. Ventriculography by the posterior approach b in Fig. 1.
3. Ventricular tap by anterior approach c in Fig. 1.
4. Posterior parietal approach a in Fig 1."








In *5* the position of the incisions on either side of the midline is shown 8 cm. above the external occipital protuberance and 3 cm. on either side of the midline. These measurements may be made with a sterile steel rule.

In *6* a McKenzie and Hudson type of burr are making openings. In *7* the two openings have been made. Dural bleeding has been stopped, as well as bleeding from the bone, by means of bone wax. At *a* the dura is incised just far enough to permit the passage of a dural elevator-hook. At *b* the dural elevator is introduced and the dura is nicked over it. At *c* the opening in the dura is coagulated so as to produce a union between dura and underlying brain tissue. At *d* the opening in the dura is ready for puncture by the ventricular needle.

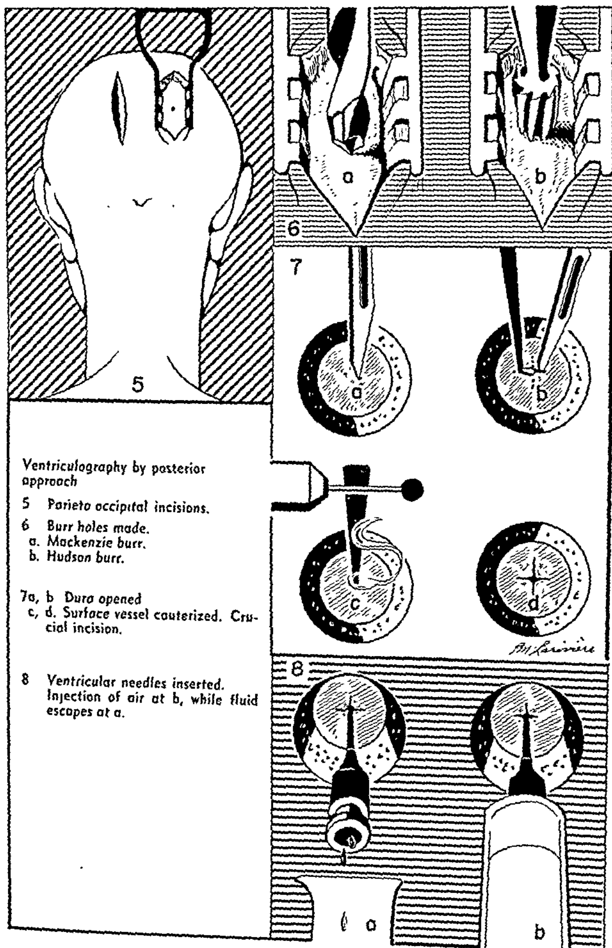
At *8* the ventricular needle, or brain cannula, one on either side, is introduced into each lateral ventricle. The cannulae are usually held in place with one or two cottonoids or bone wax applied into the burr openings. At *a* the cerebrospinal fluid from the cannula is collected, while at *b* air or oxygen is introduced into the opposite ventricle

After completion of drainage of cerebrospinal fluid and air or oxygen replacement, the stylet is returned to one cannula and air injected through the opposite needle At the completion of the injection the needle and syringe are withdrawn at the same time A similar injection of 10 cc of air and removal of the needle is done on the opposite side. When little fluid is contained in the ventricles introduction of air under mild positive pressure is necessary to obtain diagnostic filling for roentgen study.

In those cases where ventricles contain very little fluid and a positive pressure injection is employed, changes in the conscious state, pulse and respirations of the patient must be carefully observed.

Following the roentgen studies the air is removed *immediately by reinsertion* of one cannula into the larger ventricle. A brief hiss of air with several drops of fluid usually results When a mass lesion has been ascertained it is best to continue with the definitive procedure immediately.

The dural opening for ventriculography should be small but wide enough *to inspect the surface of the brain.* It is *important* to sear the dural edge to the brain in order to lessen the possibility of subdural bleeding which may occur, particularly when there is no increase in intracranial pressure




Ventriculography by posterior approach

5 Parieto occipital incisions.

6 Burr holes made.
a. Mackenzie burr.
b. Hudson burr.

7a, b Dura opened
c, d. Surface vessel cauterized. Crucial incision.

8 Ventricular needles inserted. Injection of air at b, while fluid escapes at a.

In ancient times scalp incisions were used for the primary purpose of trepanation or perforation of the skull. A circular saw with a central pin, which was termed a modiolus, was usually used. A perforator less commonly used was termed a terebra or exfoliator (Celsus). Such skull openings were indicated in compound depressed puncture fractures and other unknown conditions. Later they were employed for collections of blood or pus beneath the skull and in epilepsy. In prehistoric times the scalp and bone were evidently subjected to cauterization, a method later used by the Arabians. The skull was exposed by means of a semilunar, T-shaped, V-like or crucial incision. The practices of the Hippocratic period continued to be employed until the 19th century, according to Mettler.[303]

Wagner employed a scalp incision in the shape of the omega, the enlargement of which corresponds to those of the present period. The enlarged quadrangular flaps of Horsley[227] were followed by the still larger curved hemicraniotomy incisions of Jonnesco[258] and Doyen[125].

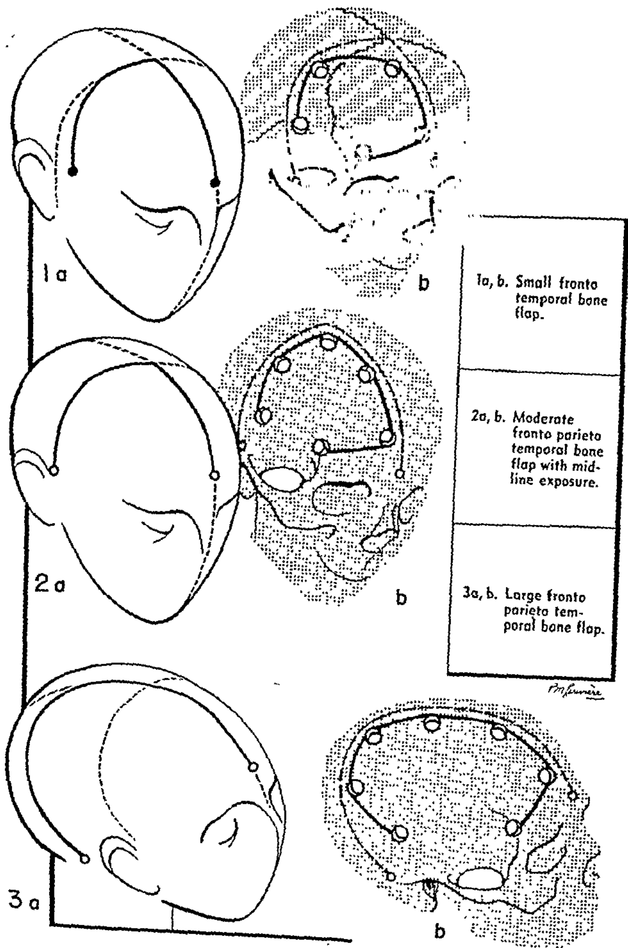
The scalp being rich in its blood supply, incisions were limited. Until recently, tourniquets were used to reduce the circulation which reaches the scalp bilaterally from the frontal, temporal and occipital areas. Tourniquets about the scalp were favored for many years, with some being more complicated than others. The Rawling's tourniquet was a flat, flexible, metallic type tightened by means of a front screw and held in front and back with a median tape over the scalp. Simpler ones employed hollow rubber tubes or the Esmarch flat rubber band. Deep sutures were sometimes used to hold this type in position.

In *1a* and *b* a small frontotemporal craniotomy, used for exposing anterior fossa lesions, such as pituitary and sphenoid ridge tumors, is illustrated.

For decompression of an orbital roof, the same incision and bone flap may be used.

In *2a* and *b* a larger bone flap is shown, with the skull perforated in six places, exposing the frontal, a portion of the parietal and temporal lobes of the brain. Exposure of the pituitary region for vascular lesions, in operations where elevation of the temporal lobe is desirable and in instances where portions of the frontal or temporal lobes may be removed, this larger opening is adequate.

In *3a* and *b* a craniotomy is shown for exposure of the temporal, parietal and frontal lobes of the brain. Such an osteoplastic craniotomy may be used for massive resections and hemispherectomy. In instances where a tumor is not precisely localized by surgical diagnostic measures, a rule of allowing an adequate exposure must be applied. This confirms an early observation made by Doyen who employed large exposures assuming that "cerebral localization in the future would only be of interest to the physiologist and no longer necessary to the surgeon" Obtaining additional room by removing bone beyond the limits of the bone flap results in undesirable skull defects When covered by muscle as in the temporal and suboccipital regions, bone removal is then permissible. The patterns presented allow for the preservation of the blood supply to the scalp


1 a
b
2 a
b
3 a
b
1a, b. Small fronto temporal bone flap.
2a, b. Moderate fronto parieto temporal bone flap with mid-line exposure.
3a, b. Large fronto parieto temporal bone flap.



In *1a* and *b* the incision and the openings made in the skull for a parietal flap are shown. When the lesion is definitely localized to the parietotemporal area, such an exposure may be advantageous.

For a parietal exposure, the patient is placed on his side, and the positioning of the head is easier.

In *2a* and *b* an occipitoparietal exposure is shown. The openings extend to the midline. The occipital pole of the hemisphere may be well visualized and mobilized in cases where lobectomy of the occipital lobe is desirable. Through such a craniotomy, intraventricular exploration may also be carried out. With an occipitoparietal exposure it is best to have the patient prone, with the head turned to a suitable position. In this position the head remains fixed in the desired relationship.

A careful planning of the incision in relation to the midline is a preoperative requirement. When a parasagittal exposure is desirable the craniotomy is extended to the midline or beyond it, if needed.

In outlining the incision one should scratch the midline posteroanteriorly or anteroposteriorly, depending upon whether an anterior or posterior exposure is needed. The skin incision for the particular craniotomy then can be outlined in relation to the midline scratch. This is particularly important in parietooccipital bone flap incisions. Because of the position of the head, one can easily mistake relationships with a resulting inadequate exposure.

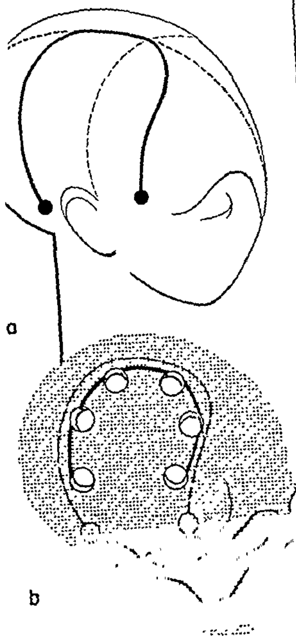
In some clinics it is customary to make smaller osteoplastic craniotomy exposures. Where a lesion is well localized this may be desirable but, in the majority of cases, a large opening is generally preferred

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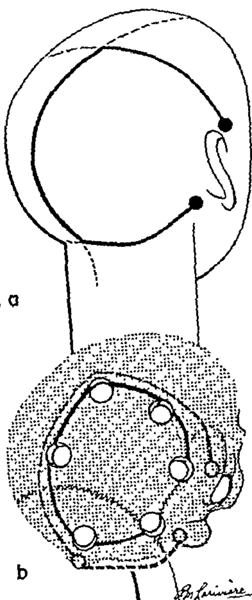
*Local Anesthesia of the Scalp*

The scalp may be anesthetized by blocking certain nerves or by general infiltration with ½ of 1 per cent procaine hydrochloride solution The supraorbital and supratrochlear nerves can be blocked by injection of 1 to 2 per cent procaine hydrochloride solution into the supraorbital notches on the two sides and the intervening portion of the scalp. This results in a rather large area of anesthetized skin adequate for repair of lacerations of the midline forehead and vertex, and cases with compound depressed fractures in this vicinity. By also blocking the branches of the auriculotemporal nerve in front of the ear and above the zygomatic arch a rather extensive area of anesthetized scalp is obtained extending from the brow nearly to the coronal suture. Blocking the posterior auricular in the vicinity of the mastoid process and the greater and lesser occipital nerves on both sides at the superior nuchal line results in anesthesia of the skin from the region of the superior nuchal line to the vertex of the head.

1a, b. Parieto temporal bone flap.




2a, b Parieto occipital bone flap.



## Incisions and patterns for osteoplastic craniotomies —concluded

## Sub-temporal decompression



In *1* the incision for a subtemporal decompression is shown. A large opening in the skull can be made by retraction of the temporal muscle with a Cushing subtemporal retractor. An opening three or four inches in diameter can be made by removing small bites of bone with a rongeur. The decompression is completed by stellate dural incisions.

Horsley[229], in 1890, pointed out that relief of cerebral symptoms may be obtained by removal of bone from the skull. It was then recommended by Sahli that the operation be done over a silent area. Paul, in 1894, used the right temporal area The right parietal area was more commonly used, according to Saenger. Cushing[75], in 1902, indicated the advantage of muscle protection and used the present operation of subtemporal decompression.

In *2* a bifrontal craniotomy is shown. The skin incision is a coronal one from temple to temple, the flap being reflected forward over the brow. The exposure of the floor of the anterior fossa in instances of cerebrospinal fluid rhinorrhea and in midline tumors, such as the olfactory groove meningiomas, is possible by this route. The skull flap may be attached to one temporal muscle, usually the right. In crossing the midline there may be active bleeding from the longitudinal sinus. It may be more advantageous to have burr openings on either side of the midline for the easier reflection of the dura and sinus off the inner aspect of the bone.

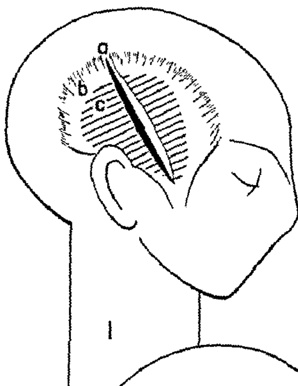
In *3* a bilateral frontotemporal flap is shown for exposure of both frontal lobes, the anterior fossa, and the midline structures in the anterior fossa. The difference between *2* and *3* is the formation of two bone flaps, each being attached to the temporal muscle on the ipsilateral side. This gives an excellent exposure of structures in the midline, including tumors attached to the anterior portion of the falx, tumors in the neighborhood of the crista galli, olfactory groove and pituitary regions. In some instances, vascular lesions involving the anterior cerebral artery may be attacked through such an opening. The same coronal scalp incision is used as in *2*, from temple to temple.

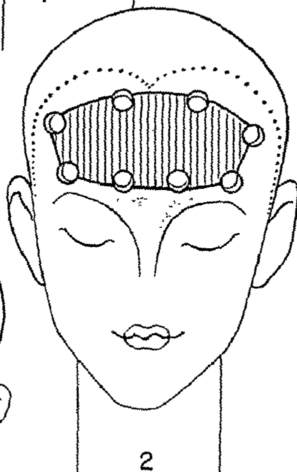
The advantage of the bifrontal flap was early recognized and discussed by Hartley and Kenyon in 1907. This type of exposure was recommended in "most tumors situated in the neighborhood of the optic chiasm, the beak of the corpus callosum and internal surface of the frontal lobes, or supraorbital surface of the frontal lobes".

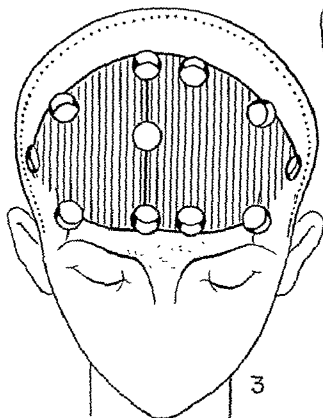
1. Subtemporal decompression.
   a. *Incision.*
   b. *Temporal muscle.*
   c. Extent of craniotomy.

2. Bifrontal bone flap with temporal muscle attachment on one side.

3 Bifrontal bone flap with temporal muscle attachments on both *sides*



To illustrate the technique of an osteoplastic craniotomy a temporoparietal exposure may be used. The opening of the skull is at this period a standardized procedure with unimportant technical variations. An important surgical problem presents itself when the dura is opened and exploration reveals an underlying neoplasm.

For a parietal exposure, with the head positioned and the patient lying on his side, the scalp may be infiltrated with ½ of 1 per cent procaine hydrochloride *solution about the projected incision.*

*No. 1* shows the position of the scalp incision for a parietotemporal bone flap. It is important to extend the scalp incision and the opening in the skull to the midline. To insure this, the midline should identified before the incision is outlined, by light scratching with a scalpel.

Anterior and superior to the ear, the skin incision may involve the superficial temporal artery or its branches. This artery and its branches may be cut at one or several points in the incision. The vessel ends should be isolated and coagulated, or securely ligated.

In the lower portion of the anterior limb of the incision one should take care not to extend the cut into the temporal fascia and muscle.

*No. 2* shows the beginning of the anterior limb of the incision and the technique of hemostasis. Hemostats are applied to the subcutaneous aponeurosis or galea along the outer aspect of the incision at *b*. Michel clips are applied to the edge of the reflected portion of the skin flap at *c*. The *incision is extended down to the subaponeurotic tissue. Digital pressure is* applied upon either side of the incision to aid hemostasis.

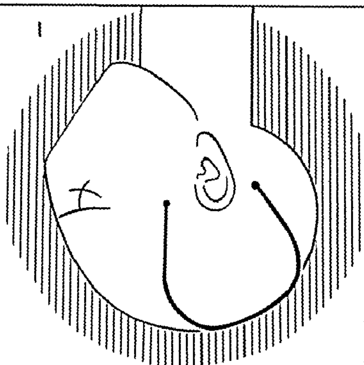
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*The Galea Aponeurotica*

The galea aponeurotica is found under the fibrofatty superficial fascia of the scalp. It is attached to the occipitalis muscle posteriorly and the frontalis muscle anteriorly, and where these muscles are wanting or not well developed, the aponeurosis extends toward bony attachments, such as the superior nuchal line and the occipital protuberance. The anterior and superior auricular muscles, if present, arise from the galea aponeurotica. The subaponeurotic areolar tissue is loose and of varying quantities in different individuals, but it permits the fairly free movement of the scalp. *A subaponeurotic infection or hemorrhage* may elevate the entire scalp off the pericranium and its limits can be the superior nuchal line and the external occipital protuberance posteriorly, the orbital rims anteriorly, and the vicinity of the zygomatic *arches and the mastoido-parieto-occipital* junction laterally. The galea in some patients is thick and strong, and along with the subgaleal areolar tissue, may be a membranous structure which can be utilized as a free graft to repair dural defects, particularly over the convexity of the hemispheres

1. Position of proposed incision

2 Incision being made.
a. Knife.
b. Hemostats on galea.
c. Michel clip for hemostasis.





In *1* the position of the scalp flap, after it has been separated from the *subaponeurotic tissue, is shown. One sees the cross-sectional* view of the gauze roll which is placed immediately under the flap. Moist gauze or a square of gutta-percha may be used to cover the secured scalp flap.

In *2* the technique for reflecting the scalp flap is shown. In *b* the scalp is grasped with a forceps or the fingers. As shown in *c* the subaponeurotic tissue is sharply incised. It is important to extend the reflection of the scalp flap into the temporal region for adequate exposure of this area, particularly if a subtemporal decompression be contemplated. The scalp is undermined at *d* with a knife being passed along its undersurface, freeing scalp from pericranium. At *e* the position of the hemostats grasping the galea is shown. At *a* the gauze roll used to hold the skin flap as shown in *1* is in position.

The pericranium is variously developed in different individuals. This layer of tissue should be preserved, notwithstanding the fact that at the incisional site it may be incised. It is thinnest in the frontal area of the *skull.*

The undersurface of the scalp may present many bleeding points. These are coagulated after carefully grasping the bleeding points in a bayonet forceps and holding the bleeding point away from the flap. This avoids injury to the scalp by the coagulating current. In the temporal area, connecting vessels between the undersurface of the scalp and the temporal fascia may be torn and should be coagulated.

The scalp flap should be observed for the presence of other bleeding points and if necessary, the coverings are removed and bleeding points are arrested before proceeding.

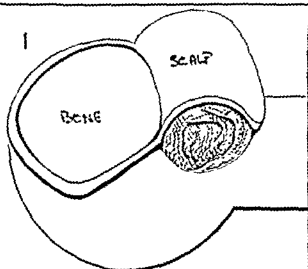
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### *The Falx Cerebri*

The falx cerebri is a dural membrane which separates the cerebral hemispheres. In front, it is attached to the crista galli and is narrow, whereas, *posteriorly*, it becomes broader and it is attached to the upper surface of the tentorium. It is a midline structure and its upper convex margin contains the superior sagittal sinus. Its lower free margin is concave anteriorly and contains the inferior sagittal sinus. The falx is attached to the midline skull from the crista galli to the internal occipital protuberance.

1. Position of head and scalp flap over gauze roll.

2. Scalp flap being raised.
  a Gauze roll.
  b Skin flap covered with gauze.
  c. Subaponeurotic tissue cut.
  d. Gentle undermining of skin.
  e. Hemostats held together.



In *1* the site of the scalp flap, the position of the temporal muscle, the incision into the pericranium exposing the bone, and the incision in the temporal muscle to expose the bone in the temporal area are shown. Posteriorly, the temporal muscle is incised parallel to its fibers. Anteriorly, some of the temporal muscle fibers may be cut transversely. The dots in *1* represent the points for perforation in the skull.

In *2* at *a* moist gauze secures the scalp flap which may first be covered with a square of gutta-percha over a gauze roll. Hemostats or towel clips at two or four points fix the gauze tightly to the drapes of the operative site. At *c* the bone is exposed by reflecting the pericranium. At *b* the incision at the temporal fascia and muscle anteriorly to expose the bone in this region is demonstrated. Several small vessels are cut by this procedure. Coagulation of these bleeding points is usually necessary. At *g* the temporal muscle has been separated posteriorly and is retracted to permit the drilling of the skull and show the burr hole. In *d*, *e* and *f* the various sized perforators are shown. The perforator *d* is used first, followed by the burr at *e* and *f* at each opening When the opening has been completed a small cottonoid can be placed within it to help in hemostasis. At times, there may be large bleeding channels in the wall of the trephined bone. Under this circumstance suction for good visualization, followed by the use of wax for sealing the venous channel in the bone is satisfactory.

Care should be taken not to disrupt the temporal muscle attachment of the bone flap.

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*The Middle Meningeal Artery*

The middle meningeal artery is a branch of the mandibular portion of the internal maxillary artery which is one of the terminal branches of the external carotid artery. It enters the cranial cavity through the foramen spinosum and it extends laterally and forward in the meningeal groove of the greater wing of the sphenoid and divides into an anterior and posterior branch. The anterior branch is larger and after crossing the greater wing of the sphenoid it enters the groove on the internal surface of the parietal bone and then terminates into several branches The posterior branch extends backward on the temporal bone and thence to the parietal bone. The posterior branch of the middle meningeal is the vessel which is frequently encountered in subtemporal decompressions and in trigeminal rhizotomy by the temporal route

The accessory meningeal artery which is inconstant may be found entering the cranial cavity through the foramen ovale. It is a branch of the internal maxillary artery but at times it may be a branch off the middle meningeal artery It supplies the neighborhood of the trigeminal ganglion and root, as well as the dural lining in this vicinity.

1. Incision of temporal muscle and periosteal lining—burr holes.

2. Temporal muscle, periosteum being incised; burr holes being made.

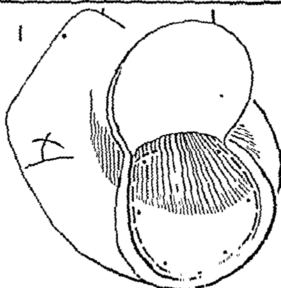
a Towel clip

b Incised temporal muscle.

c Periosteal elevator.

d, e, f. Burrs used

g Burr hole made.




2

a
b
c
d
e
f



*In 1* the positions of the perforations in the *skull* and the projected sections between the perforations are shown. In *2* the method of sawing the bone preparatory to turning the bone flap is shown. At *a* the use of the DeVilbiss rongeur to cut the bone anterior to the opening of the skull is demonstrated. At *e* the DeVilbiss has already been used, having taken several bites in the bone. In order to protect the dura a dural elevator is used to separate dura from bone before the DeVilbiss is introduced. Active bleeding may result from tearing of branches of the middle meningeal artery. This is controlled with electrocoagulation, while suction keeps the field *clear of blood. At times, the dura may* be thinned or adherent to the bone. Careful handling usually results in uncomplicated dura-bone separation.

In *b* the use of a dural elevator to separate the dura from the bone is demonstrated and at *c* one sees a dural protector passed from one opening into the next, while the saw guide, carrying with it a Gigli saw, is shown. At *d* the Gigli saw is seen cutting the bone. Occasionally a DeVilbiss rongeur is used between consecutive holes in the skull when the dura fails to separate from the bone, but this is infrequent.

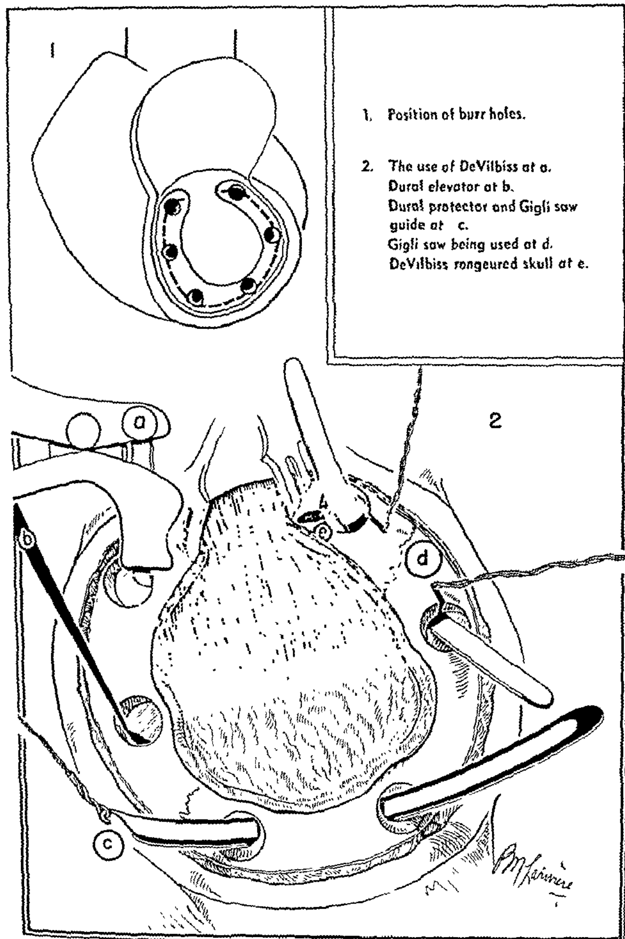
When sawing the bone the saw is angled downward to produce a bevel of the cut bone edge. When the bone flap is replaced it is then secured by the bevel. With the drawing of the wire saw with the right and left hand, at a 45 degree angle, the cutting proceeds while saline solution is irrigated over this region to reduce the frictional temperature.

In general, it is best to saw through the avascular portions first, leaving the vascular area, usually near the midline, to the last to reduce bleeding. Although not shown in the accompanying figure the openings in the skull are covered with moist cottonoid, until such time as sawing of the bone begins.

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*The Anterior Cerebral Artery*

The anterior cerebral artery is given off from the internal carotid just as it enters the lateral cerbral fissure. It passes medially and forward superior to the optic nerve and at the beginning of the longitudinal fissure where it communicates with its fellow on the opposite side through the anterior communicating artery. The two anterior cerebral arteries now run together in the longitudinal fissure, curve around the genu of the corpus callosum and extend posteriorly on the upper surface of this structure all the way to the splenium The anterior cerebral gives off the frontopolar branch (anterior medial frontal), the intermediate medial frontal branch or the *callosomarginal and the* posterior *medial* frontal branch or the pericallosal arteries. These supply the orbital surface of the frontal lobe, the superior and middle frontal gyri, the cingulate gyrus, the upper part of the precentral gyrus, the precuneus and the adjacent lateral portion of the hemisphere


1
2
a
b
c
d
e
1. Position of burr holes.
2. The use of DeVilbiss at a.
Dural elevator at b.
Dural protector and Gigli saw guide at c.
Gigli saw being used at d.
DeVilbiss rongeured skull at e.

The head is shown with the bone flap elevated in *1*.

*In 2 the method of elevating the bone flap and* permitting its inferior portion to break in the temporal area is shown. At *a* the use of counter pressure by the assistant in the region where the break should occur is *indicated*. At *b* the use of bone chisels to elevate the bone flap is shown. As the bone flap is elevated it is important to inspect the separation of the dura from bone. In some instances these structures may be adherent, resulting in dural tearing if caution is not used. If a linear break in the bone does not occur at *a*, the type of break is noted and adjustments gently made so as to prevent tearing of the dura and brain by sharp, uneven edges of the bone flap base.

When the bone flap is elevated the surface of the dura may bleed profusely. The dura is covered with a sheet of moist cottonoid, while the bone flap is covered with moist gauze and draped out of the field. The inner surface of the bone flap may present bleeding points. These may be coagulated with a high cutting current. Diploic canals which bleed profusely along the cut edge of the bone may be plugged with bone wax.

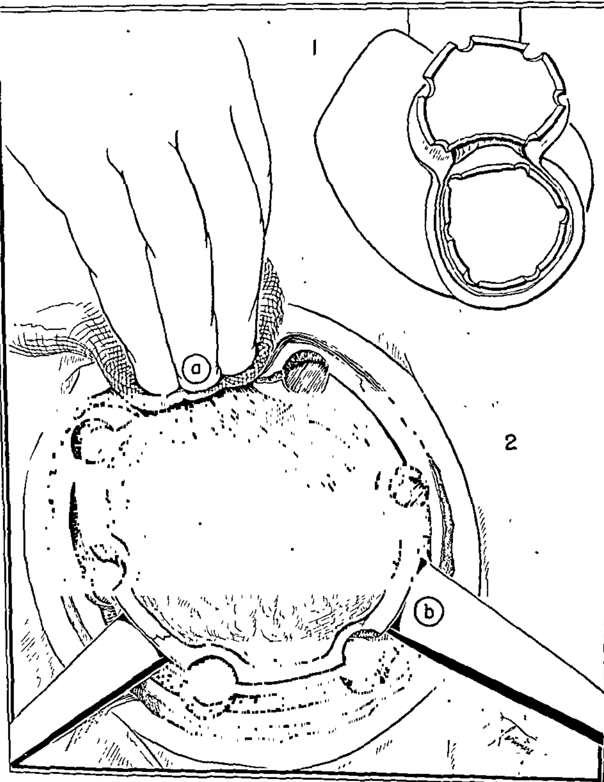
At this juncture, when the dura is exposed, the operative field is redraped. *This may be done by suturing four towels about the opening in the skull* and covering the lower portion of the area with a sheet.

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*The Choroid Plexus*

The choroid plexus is found in the lateral ventricle, in the third ventricle, and in the fourth ventricle. It is very vascular, consists of pia mater which projects in the ventricular cavity and is covered with ependymal lining. In the lateral ventricle, the choroid plexus extends from the interventricular foramen or the foramen of Monro posteriorly through the body of the ventricular cavity and thence to the *inferior horn* down to its tip. It is attached to the choroidal fissure. At the junction of the body and the *inferior horn* of the ventricle, the choroid plexus presents an area of enlargement which is *called the glomus. At times*, there may be calcification in the glomus and these may be seen in roentgenograms and should not be considered pathological. The glomus may *also cause a shadow in air studies, resulting in a false impression of an in*traventricular tumor. Small, tuft-like projections in the roof of the third ventricle and also of the fourth ventricle are found which constitute the choroid plexuses of the third and fourth ventricles respectively. The choroid plexus receives its blood supply from the anterior *choroidal* artery, a branch of the middle cerebral and posterior choroidal arteries from the posterior cerebral. Venous drainage of the plexus is through the choroidal veins which empty into the internal cerebral veins, which in turn join to form the great vein of Galen, the latter emptying into the straight sinus at the anterior border of the tentorium cerebelli

1. Bone flap completed.
2. Bone flap being elevated.
   a. Pressure at temporal area
   b. Chisels are used to elevate bone flap causing bone to break at a.



In *1* is shown the head with the bone flap elevated, the position of the deformed ventricle and the cannula inserted into the posterior portion of the ventricle.

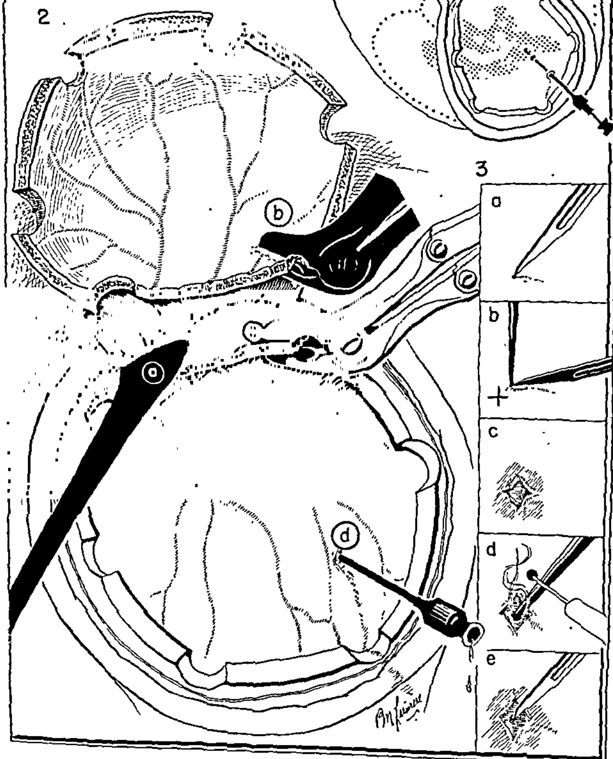
In *2* the bone flap is held while the temporal portion of the skull is exposed with a periosteal separator as shown in *a*. At *b* a portion of the bone may be removed from the flap as well as the temporal region, *c*, for a subtemporal decompression. At *d* the dura has been crucially incised and a brain cannula inserted into the lateral ventricle to relieve the increased intracranial pressure.

In *3* the method of opening the dura preparatory to entering the ventricle is shown. At *a* the dura is incised. At *b* a dural elevator is inserted under the dura and a sharp-ended knife is used to cut the dura in a crucial manner over the dural elevator shown in *b* and *c*. The bulging brain surface may now be cauterized and a sharp-ended knife blade used to incise the surface as shown in *d* and *e*. The cannula is cautiously inserted into the body of the ventricle. The needle may be directed toward the opposite orbitotemporal junction. As the ventricle is entered a difference in resistance is transmitted to the cannula. If the ventricle cannot be entered at this point, because of the proximity of a tumor mass, then a more anterior approach may be used. The temporal horn of the ventricle may also be utilized for drainage of the cerebrospinal fluid. If the ipsilateral ventricle is small or deformed it then becomes necessary to tap the opposite ventricle which may be enlarged. This will be apparent from the air study. The presence of the parietooccipital opening on the opposite side will make it an easy matter to tap the opposite ventricle.

In some instances the brain cannula, while seeking the ventricle, may enter a gliomatous cyst, thus accurately locating the position of the tumor mass.

Several bleeding points may be encountered from the main trunk or the branches of the middle meningeal artery in the temporal area. These are individually located by suction and either cauterized, clipped or ligated with silk.

In doing a subtemporal decompression the thinner portion of the temporal bone is removed in its entirety as shown in *2c*. Such an opening extends inferiorly almost to the zygomatic arch. It affords an adequate decompression if needed. After removal of the bone the edge of the skull should be felt with the index finger, noting any sharp ends which can then be rongeured away. Meticulous care should be used to remove all fragments of bone from this region by direct inspection while retraction of the temporal muscle is done by the assistants Simultaneous suction and good lighting will aid in this inspection.


1. Position of ventricle.
2a. Temporal muscle separated.
b, c. Subtemporal decompression.
d. Brain needle in ventricle.
3a, b, c. Crucial incision.
d. Cautery
e. Incision
for tap of ventricle.
1
2
b
c
c
a
d
3
a
b
c
d
e



In *1* the site of the bone flap, the position of the incised dura, the subtemporal decompression and incisions of the dura, are shown.

In *2* at *a* the draping of the bone flap is shown. The bone flap may be covered with moist gauze and firmly grasped with two large towel clips, which are held together with several rubber bands. With another towel clip a loop of the rubber band is fixed to the overhanging drapes, thus holding the bone flap away from the operative field. At *b* one method of hemostasis is shown. The branches of the middle meningeal artery are doubly ligated with silk, preparatory to opening the dura. At *c* the electrocautery is used for control of the bleeding. Since the electrocautery causes contraction of the dura at the point of contact, it should be used sparingly on the dura. At *d* the use of silver clips is shown as a means of hemostasis. At *e* the technique of the dural incision is shown. Here a strip of cottonoid is first introduced under the dura. The scissors are used to cut the dura over the cotton. As the incision is continued the cottonoid serves to protect the surface of the brain.

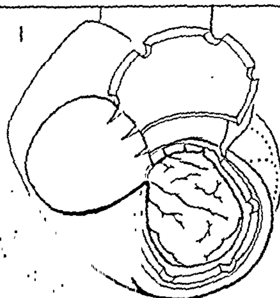
At times the dura is extremely taut, even after the ventricle has been tapped, with escape of a few drops of cerebrospinal fluid. A tap of the opposite ventricle may be advantageous. The dural incision may be attended by bulging of brain with laceration of its surface. Under such circumstances the dura is cautiously, but quickly and widely opened If the dura is tight preliminary tap should be done for a cystic lesion. If no cystic mass has been found a solid tumor would be best treated by wide incision of the dura with exposure and excision of the tumor mass or of a lobe infiltrated by tumor

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*Cranial Arachnoid*

The arachnoid membrane of the brain is made up of white fibers and elastic tissue. Both its outer and inner surfaces are covered with a low cuboidal mesothelial lining. The arachnoid membrane is almost avascular and since it is very thin, it may act as a semipermeable membrane. It loosely covers the brain but does not dip into the sulci between the convolutions. The arachnoid membrane is much thinner over the convexity of the hemisphere and thicker and more opaque toward the base of the brain There are many trabeculae throughout the subarachnoid cavity, and these trabeculae, which become continuous with the pia, are also made up of white fibers and yellow elastic tissue. The subarachnoid cavity is the space between the arachnoid and the pia mater In the sulci, the cavity is very much more evident than over the convolutions, where pia and arachnoid are in juxtaposition In certain parts of the base of the brain, the arachnoid is widely separated from the pial lining and these spaces are named the subarachnoid cisterns

1. Dural flap.
2. Opening of dura
   a Bone flap held with clip.
   b. Meningeal vessels doubly ligated.
   c. Cautery.
   d Silver clip.
   e. Dura incised over cottonoid.



A meningioma has its origin from cells in the leptomeninges, and more particularly, in the arachnoidal granulations. Usually slow-growing, it may attain a surprisingly large size. It remains encapsulated and exerts pressure with deformation of the cerebral tissue as the mass consumes space. The meningioma usually occurs in the later age groups, rarely in childhood. Although this encapsulated mass is usually composed of typical endothelial or meningothelial cells, differentiation may result in angiomatous, sarcomatous, or a mixed variety of cells, thus producing a malignant growth, with recurrence of the tumor and early death.

Meningiomas may grow most commonly as a circumscribed, globular mass, but en plaque and hyperostosing forms are also common. The hyperostosing type deserves special attention in that all of the bone involved must be removed in order to eradicate the tumor growth. At times, a whole bone flap may have to be discarded. Under these circumstances tantalum or lucite may be used for cranioplasty.

Parasagittal tumors of the meningioma type are common, occurring in twenty-five per cent of this group. The term "parasagittal" was first suggested in 1922 and was adopted by Elsberg[136] in 1931. These are grouped into three locations; those involving the anterior, those involving the middle and still others involving the posterior third of the skull in relation to the sagittal sinus. The middle third is a common site for the global type of parasagittal meningioma. Two types of parasagittal tumors are common; those of the global type, and those of the hyperostosing type The old term for the hyperostosing type is "fungus durae matris."

The famous case of General Leonard Wood was that of a parasagittal meningioma, illustrative of the problems which such a tumor presents. He was operated upon by A. T. Cabot in 1905 at which time a tender protuberance on the skull was investigated under anesthesia. A circle of bone was removed and the normal-appearing dura was not opened. The diagnosis of psammoma of the diploe was made. In 1910 he was reoperated by Dr. Cushing[93] By means of an osteoplastic flap a centrally placed parasagittal tumor was removed which weighed 198 grams. Operation for recurrence was done in 1927, at which time a recurrent 350 gram meningioma was again removed with death resulting.

Cushing[93] has pointed out that "parasagittal tumors prove to be adherent to the dura under the vault over a considerable area They sometimes extend downward along the falx. Indeed, in some instances they may have a bilateral disposition. Great caution must be taken to determine whether hyperostosis or invasion of the bone is present, since recurrence may be a threat unless this tumor tissue is also completely removed".

The hyperostosing parasagittal meningioma is an interesting tumor and has long been recognized. Other terms describing it have been "hemicraniosis" and "perforating tumors of the skull". There are pictures in the older literature that attest to the recognition of this skull lesion and there are records that these tumors have been operated upon. There are examples found in Peruvian skulls reported in studies on paleontology. The hyperostosing meningioma produces predominant changes involving the bone. This is in distinction to the global type of meningioma which may produce only minimal hyperostosis. The early operations upon these tumors were uniformly unsuccessful. It was not uncommon for the hyperostosis to be incised with resulting extrusion and ulceration of the tumor mass.

It is important that hyperostosing tumors, presumably of the en plaque type at the outset, may in the course of time give origin to soft, invasive global tumors. It should also be kept in mind that the endotheliomatous hyperostosis may be the primary tumor and may be unassociated with a subdural lesion. Alpers and Harrow have discussed such a case.

The majority of parasagittal tumors have been observed to arise from the neighborhood of the middle third of the sagittal sinus, related to the pacchionian granulations of this area. The frontal and occipital parasagittal tumors may assume quite a large size by silent growth, while those occupying the middle third are small and result in earlier symptoms and signs. The tumor's relationship to the rolandic fissure determines the clinical pattern of the disease. It is of note that Cushing[38] felt that the incidence of trauma in the parasagittal cases is significant.

Once the tumor location has been ascertained the remaining exposed brain can be carefully covered with cottonoid, moistened from time to time with warm saline.

The vascular supply of the tumor surface in relation to the surrounding tissue is carefully assessed. The border of the tumor mass medially toward the midline and laterally, anteriorly, and posteriorly should be determined. In some cases it may be necessary to remove more bone for complete exposure. When the midline structures are evidently invaded by the tumor mass it becomes expedient to rongeur away the bone from the midline neighborhood. This is always associated with large amounts of bleeding which may be controlled with gelfoam® and bone wax.

As it has been stated before, it is important to note the relation of such a tumor mass to the sagittal sinus. When the tumor mass involves the middle and posterior third of the sagittal sinus, it is essential to avoid interference with the patent sinus because of the risk of producing a profound neurologic deficit (paraplegia or quadriplegia). The only exception to this is when it is proven beyond doubt that the sagittal sinus is occluded by the tumor mass, in which case, this portion of the sinus, along with the tumor may then be excised.

Parasagittal meningioma



At *a* the dura has been reflected and it is now placed between two layers of wet cottonoid. It is important to cut the dura down to a narrow attachment and to make it a free graft so as to minimize postoperative bleeding, from the dural edge. At *b* the temporal dura has been incised, both for inspection of this region, as well as subsequent subtemporal decompression. At *c* the position of the neoplasm in the parasagittal area is indicated. This parasagittal lesion was a meningioma.

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*Sensory Nerve Supply of the Scalp*

The sensory nerves of the scalp are the supraorbital and supratrochlear branches of the opthalmic anteriorly; the auriculotemporal branch of the mandibular laterally; above and in front of the ear, the greater auricular; the greater occipital and the lesser occipital nerves posteriorly and laterally.

The supratrochlear and supraorbital nerves are branches of the frontal nerve which in turn is the largest branch of the opthalmic nerve The supratrochlear nerve is smaller than the supraorbital It leaves the orbit between the pulley of the obliquus superior and the supraorbital foramen. It supplies the skin of the middle of the forehead, the upper lid and the conjunctival lining of the upper lid. It ascends near the pericranium on the medial aspect of the frontalis muscle.

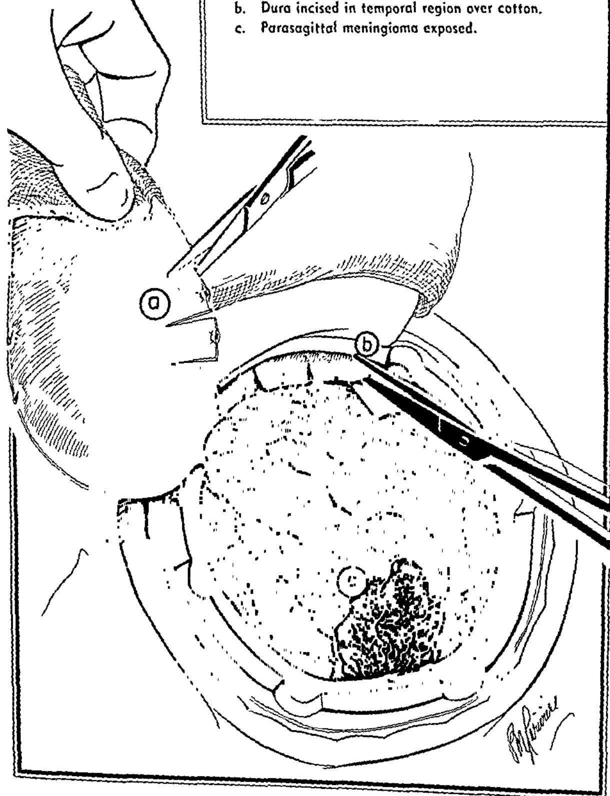
The supraorbital nerve leaves the orbit through the supraorbital foramen or notch and gives off twigs supplying the upper lid The terminal branches, the medial and the lateral extend as far back as the lambdoidal suture The supraorbital nerve is accompanied by the supraorbital artery at the notch.

The supraorbital and supratrochlear nerves may be avulsed in cases of first division trigeminal neuralgia with resultant temporary relief of the disability. The position of the supraorbital can be best estimated by palpation of the supraorbital notch. The supraorbital nerve and the artery can be exposed through a small incision in the brow. It is important not to injure the artery in attempts at avulsion of the nerve It is best to separate the nerve, dissect it free from the artery and then avulse it In this way bleeding difficult to control may be averted. The supratrochlear nerve is in a position medial to the supraorbital foramen or notch and can be found just external to the pericranium of the frontal bone of this region

(Continued on page 62)

Dural graft formed by circular incision.
Dural attachment intact in posterior parietal region.

a. Dura incised for subtemporal decompression.
b. Dura incised in temporal region over cotton.
c. Parasagittal meningioma exposed.



## Technique of osteoplastic craniotomy

### —continued

### Parasagittal meningioma

▶

In *1* the position of the tumor and the covered dura are shown.

In *2* the tumor mass, which is illustrated as a global type of meningioma, is separated from the surrounding tissues. The vessels crossing from the brain into the tumor are carefully isolated and cauterized or clipped. Cottonoid retraction and gentle dissection are employed. Traction on the tumor mass as it is gradually mobilized may be aided with stout silk sutures passed through the tumor mass. Upon gently separating the tumor from the surrounding tissues, the vessels brought into view progressively are clipped or coagulated, reducing the amount of hemorrhage during mobilization. If the tumor is large and difficult to mobilize, then a portion of its presenting area may be excised by the electroloop. After gutting the tumor mass the remaining exterior shell may be freed.

In *3* the tumor is enucleated and the brain protected with cottonoid strips. The site of the tumor, immediately adjacent to the falx, is then inspected. The presence of vessels in the tumor bed is noted and dealt with by coagulation, clips, temporary pressure with cottonoid sponges, or gelfoam®.

In these illustrations, as shown in *4*, the sagittal sinus was not involved. The tumor was separable from the falx and sagittal sinus. Small vessels on the falx, which were found bleeding after removal of the tumor, were coagulated. The involved surface of the brain was covered with a thin layer of gelfoam®.

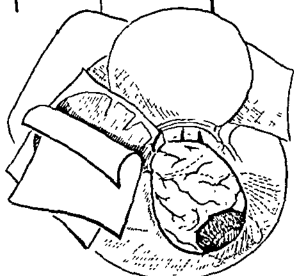
When the falx is invaded by the tumor, that portion may be excised with the tumor. When the sagittal sinus is involved the surgeon must determine the advisability of excising this portion of the sagittal sinus. As stated before, the sagittal sinus may be excised through its anterior third. The middle or posterior third, if not completely thrombosed, should not be excised since almost always a paraplegia or quadriplegia results after such ligation and excision.

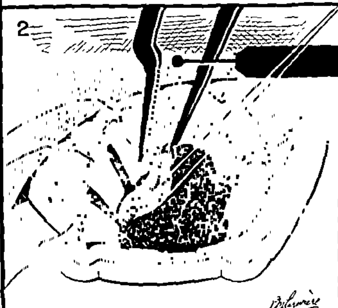
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*Sensory Nerve Supply of the Scalp* [illegible]

Th[illegible] nal [illegible] areas. The superficial temp[illegible] of the nerve accompany the superficial temporal artery to the vertex of the skull. Other branches supply the region of the ear and the external auditory meatus. At its origin, the auriculotemporal nerve is in close proximity to the condyle of the mandible. In this position it can be involved by malocclusion of the teeth resulting in slight dislocation of the temporomandibular articulation. This con-

(*Continued on page 64*)



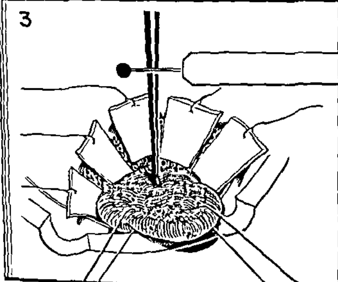



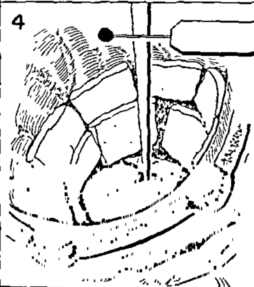

1. Dura placed between two moist sheets of cottonoid.

2. Tumor separated from surrounding brain with cottonoid dissection.

3. Tumor elevated with traction on sutures passed through its substance.

4. Tumor removed, bleeding points on falx cauterized. The tumor bed is lined with gelfoam®.



In *1* the position of the bone flap, the replaced dura and the sutures holding the dura against the bone edge are shown. The open dura at the subtemporal decompression is evident.

In *2* the dura is closed tightly with interrupted silk sutures indicated at *c*. As shown in *d* a mattress type of suture may be used to tent the dura at the bone edge to the pericranium. Midline bleeding may be reduced by this measure. Any subsequent collection of blood is restricted to the field of operation. Usually, four to five dural pericranial sutures are needed. At *b* one method is shown of drilling of a small hole in the skull to permit wire fixation of the bone flap. When the bone is thinner the drill may be used to penetrate the entire thickness of the skull, as was done in the posterior portion of this bone flap as shown in *e*. At *f* a subdural gutta-percha drain is used as shown. This drain exits through a stab wound posterior to the bone flap incision. At *a* the drill making a hole in the bone flap for the wire suture is indicated.

When the dura is involved in the tumor, and this may be the case in [illegible] the dura with normal [illegible] The dura defect may be closed by the use of temporal fascia or pericranium.

Since almost always temporal fascia or pericranium is available there is little need for the use of fibrin film, except in rare instances where the other structures have to be sacrificed.

In some instances of hyperostosing meningioma the authors have used a preformed tantalum plate to replace the discarded bone flap for the repair of the skull defect. As stated earlier, any or all of the bone flap should be discarded if there is involvement by tumor growth.

Wound closure requires special attention. By meticulous care during this step, postoperative bleeding and complications in wound healing can be minimized. Bone edges should be inspected for diploic bleeding, before the bone flap is replaced. Bleeding points in the dura at the perforations may be treated by a suture from dura to pericranium, or by the use of gelfoam. Bleeding from the bone flap may be minimized by cauterizing the inner surface of the temporal muscle in an anteroposterior line and about $\frac{1}{4}$ cm. in width.

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*Sensory Nerve Supply of Scalp (continued)*

dition may be mistaken for tic douloureux and is treated successfully by orthodontic methods for correcting the malocclusion.

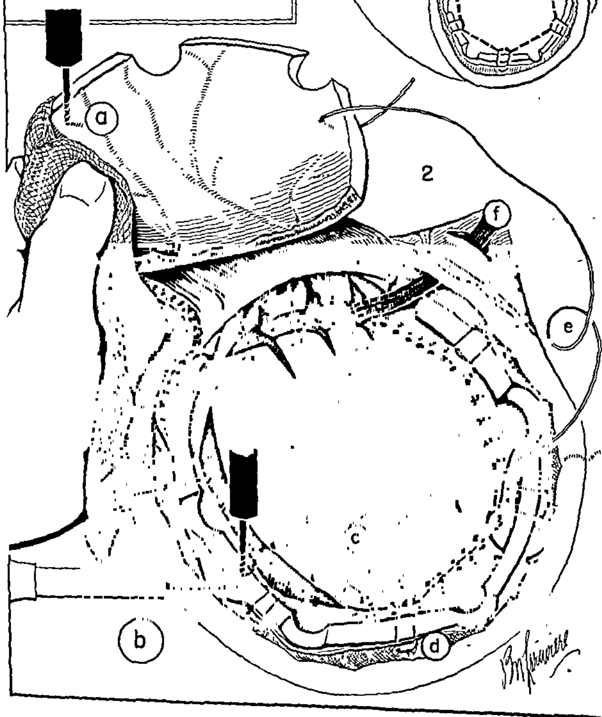
The posterior and lateral aspect of the scalp is supplied by the greater auricular near the posterior aspect of the ear, the lesser occipital and the greater occipital nerves. The first two are branches of the cervical plexus. The greater auricular and the transverse cervical may be located in a

*(Continued on page 66.)*

1

1. Closure and tenting of dura.

2a, b Drill for suture.
c. Interrupted silk closure.
d. Tenting of dura for hemostasis.
e. Wire suture.
f. Subdural drain through stab wound.



In *1* the bone flap has been replaced and fixed into a firm position by two wire sutures as shown.

*In 2 the closure of the bone flap, temporal muscle* and pericranium is shown. At *a* the wire suture to fix the bone flap to the rest of the skull is grasped with a hemostat and twisted as shown at *b*. This may now be grasped and pulled over to either one or the other holes in the bone and tucked into the skull opening. At *c* the closing of the temporal muscle and the pericranium is shown. In many instances the pericranium is thin. It is unnecessary and impossible to approximate this layer over the bone flap. Drainage of the subdural and pericranial areas, an optional method, is shown at *d*. These gutta-percha drains are removed in eighteen hours.

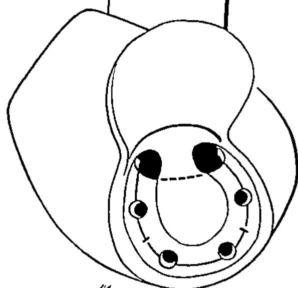
In the frontal portion of the skull, the openings may be covered by the use of tantalum clips or tantalum mesh. This eliminates the depression of the scalp over the perforations visible in the non-hairy portion of the scalp. With frontotemporal flaps the anterior burr holes may be made much smaller or a trephine may be used, replacing the button of bone at closure. This also will eliminate the depression over these openings.

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*Sensory Nerve Supply of Scalp (concluded)*

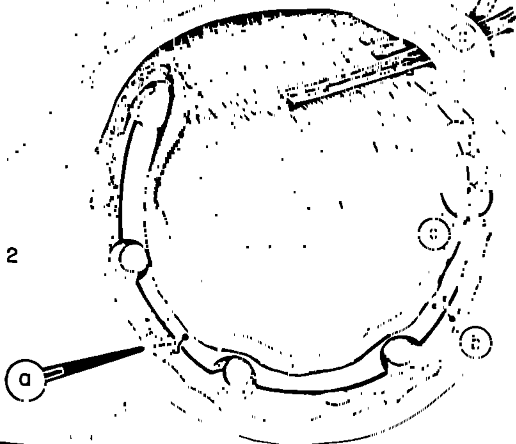
subcutaneous position on the posterior aspect of the middle third of the sternocleidomastoid muscle. At times these nerves are cut to relieve pain in patients with growths at the ear-neck junction. The transverse cervical extends anteriorly toward the midline while the greater auricular extends upward toward the ear. The latter is much larger than the former. Neither results in contraction of muscles on stimulation by electrical current. The lesser occipital arises from the second cervical. The greater occipital nerve supplies the skin of the posterior aspect of the head It is the medial branch of the posterior ramus of the second cervical nerve. It ascends on the posterior aspect of the skull in company with the occipital artery and supplies the scalp to the vertex. It also has some muscular branches to the deep muscles of the neck.

In occipital neuralgia, section of the greater occipital nerve may be performed. This is best accomplished by a transverse incision of the scalp and the subcutaneous tissues paralleling the superior nuchal line One has to secure the occipital artery by electrocautery or suture By using such an incision both the greater occipital as well as the lesser occipital are sectioned with resultant denervation of the region This is preferable to the method of isolating the greater occipital nerve alone and avulsing it.




1. Bone flap replaced.

2a, b. Wire suture.
 c. Temporal muscle and pericranium closed with interrupted silk.
 d. Subdural and subcutaneous flat rubber drains through a stab wound.





The method of closing the scalp is shown. In *1* the closed scalp with interrupted silk sutures and the gutta-percha drains in position are shown.

In *2* at *a* Michel clips are removed. At *b* bleeding points are coagulated if necessary. Wound healing depends on minimal tissue injury and a maximal blood supply, therefore, the coagulation current should not be used excessively along the edge of the skin flap. To reduce the bleeding, hemostats and Michel clips are removed in groups. During scalp closure blood loss must be reduced to a minimum.

At *c* the galea is sutured with interrupted silk sutures. At *d* the scalp is approximated with interrupted silk sutures. Silk is used for all sutures. A tight closure is essential in both galeal and scalp layers.

When drains are used, *f*, a soft plentiful dressing is applied. Tightness is avoided. In undrained wounds the dressing is removed the day after operation. The scalp is covered with a sterile surgical cap.

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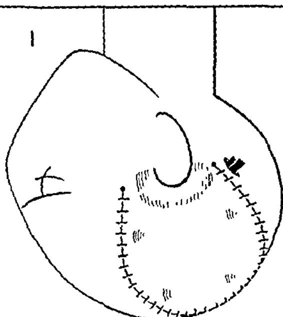
### *Temporal Bone*

The temporal bone consists of the squamous portion which forms the flat bone on the lateral aspect of the middle fossa, the zygomatic process which extends anteriorly to the zygomatic bone, the mastoid process to which externally are attached the sternocleidomastoid, splenius capitis, longus capitis and the posterior belly of the digastric muscles and posteriorly the occipitalis muscle. The styloid process, the external auditory canal and the petrous bone, or the pyramid, complete the list.

The base of the petrous pyramid is at the mastoid process, the apex toward the midline, and it fits between the greater wing of the sphenoid and the basilar process of the occipital Its anterior surface presents the tegmen tympani, a layer of very thin bone forming the roof of the tympanic cavity. Further anteromedially is the hiatus of the facial canal through which passes the greater superficial petrosal nerve. The anterior surface of the petrous bone forms the posterior boundary of the middle fossa. The posterior surface of the petrous bone forms a portion of the posterior fossa. The internal acoustic meatus is at the center. It transmits the facial nerve, the nerve of Wrisberg, the acoustic nerve and the internal auditory branch of the basilar artery. There are many other important aspects in the anatomy of the temporal bone but these do not concern us in this particular contribution.

1. Scalp flap closed. Drain through stab wound.

2a. Clips removed.
b Cautery of bleeding point.
c. Galeal stitch.
d. Scalp stitch.
e. Sutures cut.
f. Stab wound for drains.



## Olfactory Groove Meningioma

The olfactory groove meningiomas occur in about ten per cent of intracranial meningiomas. As reported by Cushing and Olivecrona[332], if suprasellar meningiomas, sphenoid ridge meningiomas, and olfactory groove meningiomas are combined, the anterior fossa basilar meningiomas represent about one-third of the meningiomas. The olfactory groove meningioma shows little tendency toward recurrence. It is a slow-growing tumor, as is evidenced

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*Subarachnoid Cisterns*

Subarachnoid cisterns include the cisterna magna, pontis, interpeduncularis, chiasmatis, the cisterna fissura cerebri lateralis and ambiens. The cisterna magna is the space between the cerebellar hemispheres and the medulla oblongata junction. This cavity is continuous with the subarachnoid cavity of the spinal canal at the level of the foramen magnum. The cisterna pontis is on the anterior surface of the pons Inferiorly, it is continuous with the subarachnoid cavity of the spinal canal and the cisterna magna; whereas, superiorly, it becomes continuous with the cistern between the cerebral peduncles or the cisterna interpeduncularis. This is the cistern between the temporal lobes and contains the cerebral peduncles and most of the circle of Willis. Anteriorly, this cistern becomes continuous with the cisterna chiasmatis over the optic chiasm. The cisterna fissura cerebri lateralis is immediately over the Sylvian fissure and contains the middle cerebral artery. The cisterna ambiens surrounds the junction of the cerebral peduncles with the hemisphere. Inferiorly, it is continuous with the cisterna interpeduncularis.

The subarachnoid cavity of the brain communicates with the ventricular system of cavities through the foramen of Magendie which is over the roof of the fourth ventricle and the foramina of Luschka, two in number, extending from the lateral recesses of the fourth ventricle into the cisterna pontis on either side, just above the emergence of the glossopharyngeal nerve from the medulla.

*Pia mater of the Brain*

The pia mater of the brain is a connective tissue covering the entire surface of the brain. This connective tissue dips between the cerebral convolutions and it is also invaginated in fetal life to form the choroid plexuses of the lateral and third ventricles, as well as the fourth ventricle The pial lining over the cerebellum is much more delicate and it is not as intimately related to the surface as in the cerebral hemispheres.

usually by a long history. Occasionally it may present calcium deposits, and the growth may be large, resulting in difficult removal. Growth in some instances may be bilateral, with posterior midline extensions which involve the anterior cerebral and the anterior communicating arteries. The olfactory groove tumors, according to Cushing, not only overlie and depress the chiasm, but "squeeze under and between the anterior cerebral vessels, separating them laterally so far as the anterior communicating branch of the circle of Willis permits. The median posterior protrusion of the growth gets tightly encircled by these vessels which may become imbedded in its substance. For this reason, accidents from sudden hemorrhage are likely to occur in what to the last moment has promised to be a successful tumor enucleation".

In roentgen diagnosis, Sosman has come to lay considerable stress on the downward depression of the ethmoidal plate in the diagnosis of olfactory groove meningiomas. Ventriculograms in the larger tumors have shown a mild hydrocephalus; a displacement, with separation of the anterior horns of the lateral ventricles and an elevation and cutting off the anterior end of the ventricles in the lateral view. These tumors have been divided by David and Askenasy into anterior, middle and posterior tumors of the olfactory groove. However, many attain a large size before operative intervention, making exact location of origin impossible. Vision is affected late by the downward growth of the tumor over the chiasm. If extirpation is to be performed safely, the early diagnosis of these tumors must be made. Early diagnosis may in the future depend upon angiography, with displacement of the anterior cerebral artery into a pattern which makes tumor identification possible and prepares the surgeon for the type and size of the tumor to be encountered.

Historically, the olfactory groove meningioma is important. Francesco Durante, Professor of Clinical Surgery at the University of Rome, performed the first successful operation upon a meningioma in 1885. The tumor removed was a unilateral olfactory groove meningioma which was described as being the size of an apple. Under chloroform anesthesia a generous osteoplastic opening in the frontal bone preceded the removal of the tumor mass. The operation lasted an hour. Perforation of the left cribriform plate by the tumor was treated by passing a drainage tube into the nose with a subsequent cerebrospinal fluid rhinorrhea. The patient was reported to have been well for twelve years when re-operation resulted in fatality.

A few words should be stated concerning suprasellar meningiomas which have been confused with olfactory groove lesions. Cushing[55] described the chiasmal syndrome caused by the suprasellar meningioma as characterized by primary optic atrophy, with bitemporal field defects in adult patients showing an essentially normal sella turcica. While optic nerve involvement characterizes the early small masses, the larger tumors result in a hydrocephalus, diabetes insipidus, and indications of hypothalamic involvement.



A frontal lobectomy may be used for the exposure of the olfactory groove meningioma; certain of the larger suprasellar or sphenoid ridge meningiomas; an infiltrating, but localized neoplasm of the lobe; for discrete but large angiomas or arteriovenous malformations involving the lobe; for an extensive scar and porencephaly. In some instances, a portion of the lobe may be excised for an internal decompression.

A frontotemporal type of craniotomy is planned for this procedure, as shown in *1*. The craniotomy is extended to the midline. The amount of frontal lobe that can be excised without causing motor and sensory deficits is 3 cm. anterior to the frontotemporal junction and the Sylvian fissure. Near the midline it is best to leave a little more of the frontal lobe. The right frontal lobe may be sacrificed with greater confidence. If necessity arises the left frontal lobe may be excised also, but the resection should be placed 4 or 5 cm. anterior to the frontotemporal junction. The medial aspect of the frontal lobe at the midline, as well as the basal surface laterally must be exposed. At the midline the veins extending into the sagittal sinus are doubly clipped or coagulated and cut. At the base laterally, and at the anterior pole, large veins and arteries are also secured. On the surface of the brain the presenting veins and arteries are doubly clipped, ligated or coagulated before incision of the frontal lobe by the electrosurgical unit is begun. If necessary, the Sylvian vein may be sacrificed. The resection is aided by the generous use of cottonoid and spatula retraction. If the anterior horn of the ventricle is entered this opening is covered with cottonoid. If the craniotomy does not extend to the midline a portion of the frontal lobe may be sucked away, allowing room to coagulate or clip the vessels at the midline. However, additional removal of bone is advisable.

In *1* the area of frontal lobe to be excised is shaded. In *2* the base *a* and the midline at *c* are visualized The vessels are clipped or coagulated at *a*, *b* and *c*. At *b* the electrosurgical current is used to incise the brain surface. The line of incision is shown by the dashes from *b* to *c*.

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*Dural Sinuses*

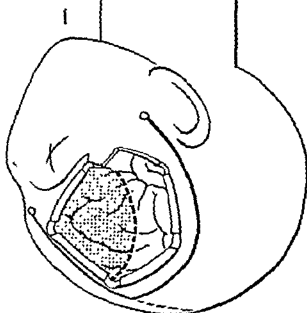
The superior sagittal sinus is triangular in cross-section and is in the convex margin of the falx cerebri. It extends from the foramen cecum in front of the crista galli of the anterior fossa to the internal occipital protuberance. It is much larger posteriorly than it is anteriorly. At the occipital protuberance it takes part in the formation of the confluence of sinuses and usually it continues into the right lateral sinus About eight to twelve superior cerebral veins empty into the superior sagittal sinus, the more anterior ones running into the sinus at right angles and the more posterior ones, at an obtuse angle. Immediately lateral to the sagittal

*(Continued on page 74)*

1. Craniotomy to the midline, imperative. Shaded area to be excised.

2a, b. Base of skull, vessels clipped and cut. a to c. Line of incision.
c Midline vessels exposed, doubly *clipped and cut.*

Near c the falx may be seen Other vessels to sagittal sinus coagulated and cut



As shown in *1* the incision of the brain is extended by blunt dissection with a piece of cottonoid grasped in a bayonet forceps. Instead suction or a lobotomy knife may be used. The finger also has been used to section the white matter. Vessels encountered may be coagulated and clipped as shown in *2*. A lighted retractor visualizes the incision. Branches of the anterior cerebral artery along the medial aspect of the hemisphere are clipped and coagulated. After the section of the frontal lobe has been completed the remaining bleeding points may now be controlled. Deep veins from dura to brain require attention. The cut surface of the frontal lobe may be covered with a thin layer of cellulose gauze.

An alternative to lobectomy for exposure of a deep-seated neoplasm, is lobe retraction which results in swelling and necrosis of the traumatized tissue. Not only does ultimate destruction occur from the damage of retraction, but the *postoperative consequences of increased intracranial pressure* may threaten or take life. The lobectomy provides an internal decompression and aids recovery in these cases.

In *3* a meningioma of the olfactory groove has been exposed.

In *4* this meningioma was excised by careful separation from the underlying dural connections In some cases fractional removal of such a tumor is necessary by the use of the electrosurgical loop. It is important not to tear the dura or traumatize it unduly at the base since a cranionasal fistula may be produced with or without cerebrospinal rhinorrhea. This may result in infection, early or delayed.

Care must be taken to avoid traumatizing the medial surface of the opposite frontal lobe, as well as to avoid injury to the left anterior cerebral artery.

When the tumor invades the bony tissue in the vicinity of the cribriform plate, excision may be associated with a cranionasal fistula. An alternate plan is to cauterize as much of this tissue as possible without damage to other surrounding structures.

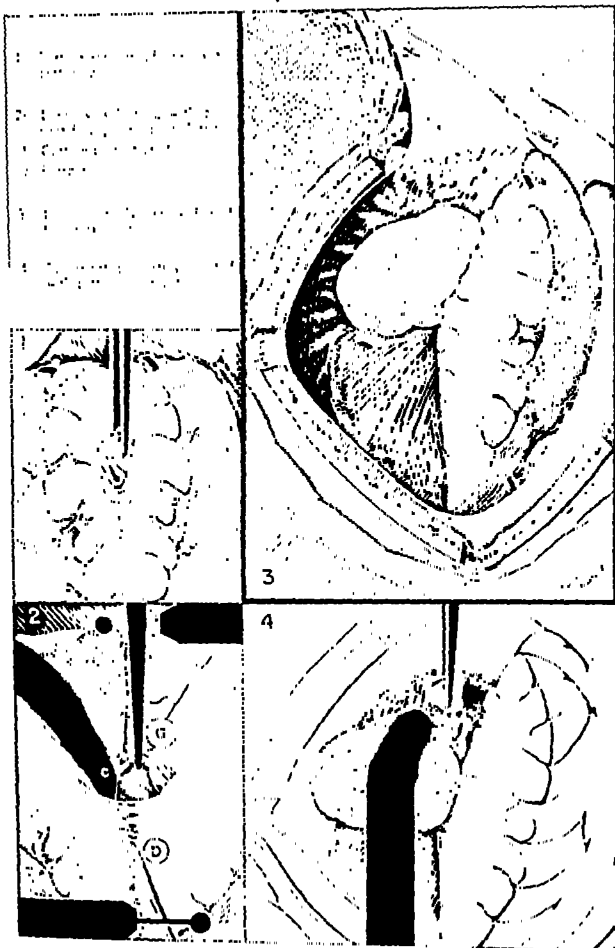
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*Dural Sinuses (concluded)*

sinus there are venous lacunae, a small frontal, a larger occipital and a very large parietal lacuna into which empty the superior cerebral veins.

The inferior sagittal sinus is found in the free margin of the falx cerebri Posteriorly, it ends in the straight sinus

The straight sinus is formed at the junction of the falx cerebri and the tentorium cerebelli. Posteriorly it empties into the confluence of sinuses Anteriorly it receives the inferior sagittal sinus and the vein of Galen. At the inferior surface of the tentorium it receives several superior cerebellar veins which are encountered at operation by exposing the superior surface of the cerebellum, near the midline.


2
C
G
D
3
4

In some cases of occipital lobe tumor, such as an astrocytoma, it may be advisable to excise the occipital lobe. These operations are mainly executed on the right side. Left occipital lobe resections must be well posterior to the supramarginal and angular gyri in order to avoid serious sequelae. In either instance, there is a homonomous hemianopsia produced which may exist prior to the occipital lobectomy due to invasion by the tumor tissue.

In *1* the medial aspect of the occipital lobe is exposed and the veins extending from the surface of the occipital lobe into the venous sinuses are coagulated or clipped and cut, *a*. At *b* the incision into the surface of the brain is carried out by the electrosurgical current The use of cottonoid at the end of a long bayonet forceps, aided by flat brain retractors to carry out further dissection of the lobe, is shown at *c*. Instead a small bore suction tube may be used. After the incision is completed and the occipital pole is removed the bleeding points on the surface are carefully coagulated or clipped and the surface of the brain is covered with a thin layer of cellulose gauze.

In *2* the lateral sinus at *a*; the sagittal sinus at *b*, and the straight sinus at the junction of the two are shown.

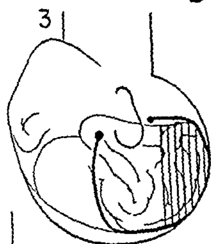
In *3* the type of incision for the craniotomy to expose the occipital lobe and the extent of the lobectomy are shown.

Water tight closure of the dura is required since the occipital pole of the ventricle is usually opened during the lobectomy. The excised occipita. lobe affords sufficient internal decompression External drains are avoidedl

### Astrocytoma

The second common member of the glioma family of neoplasms is the astrocytoma which involves the hemisphere in adults and the cerebellum in childhood. In either location the tumor is a slow-growing, usually extensively invading growth, replacing normal glial tissue. Growth in the cerebellum frequently results in the formation of a cyst of varying size. The cyst is smooth, glistening, with friable lining, and contains a light or dark brown fluid having a high protein content. It has been stated by Bailey[14] that this fluid is the product of transudation from the blood stream. Tumor tissue exists in the wall of the cyst, usually localized in a mass, recognized as a mural node. The removal of the nodule, which varies in size, is the goal of the operation. Such cerebellar cysts usually involve a cerebellar lobe and extend to the midline and may reach a remarkable size before acute distress occurs. When obstruction of the fourth ventricle occurs the increased intracranial pressure may be acute and rapidly progressive

Supratentorial astrocytomas have often been silent growths over a *period* of years rather than months. Although cyst formations may occur in this







1 Occipital lobectomy.
 a. Midline exposed, vein coagulated.
 b. Cutting current for incision of brain.
 c. Further incision.
2 Lobe removed.
 a. Lateral sinus and tentorium.
 b. Sagittal sinus and falx.
3. Scalp incision and extent of lobectomy.

In some cases of occipital lobe tumor, such as an astrocytoma, it may be advisable to excise the occipital lobe. These operations are mainly executed on the right side. Left occipital lobe resections must be well posterior to the supramarginal and angular gyri in order to avoid serious sequelae. In either instance, there is a homonomous hemianopsia produced which may exist prior to the occipital lobectomy due to invasion by the tumor tissue.

In *1* the medial aspect of the occipital lobe is exposed and the veins extending from the surface of the occipital lobe into the venous sinuses are coagulated or clipped and cut, *a* At *b* the incision into the surface of the brain is carried out by the electrosurgical current. The use of cottonoid at the end of a long bayonet forceps, aided by flat brain retractors to carry out further dissection of the lobe, is shown at *c*. Instead a small bore suction tube may be used. After the incision is completed and the occipital pole is removed the bleeding points on the surface are carefully coagulated or clipped and the surface of the brain is covered with a thin layer of cellulose gauze.

In *2* the lateral sinus at *a*; the sagittal sinus at *b*, and the straight sinus at the junction of the two are shown

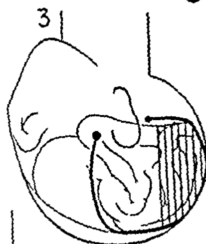
In *3* the type of incision for the craniotomy to expose the occipital lobe and the extent of the lobectomy are shown.

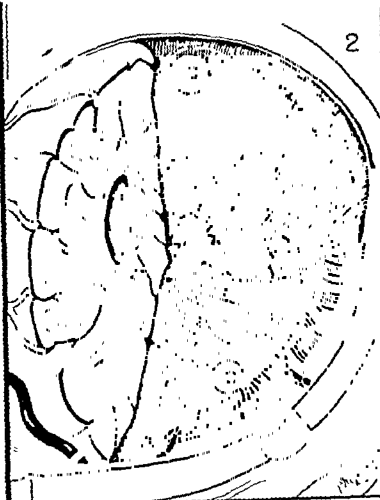
Water tight closure of the dura is required since the occipital pole of the ventricle is usually opened during the lobectomy. The excised occipita lobe affords sufficient internal decompression External drains are avoidedl

ASTROCYTOMA

The second common member of the glioma family of neoplasms is the astrocytoma which involves the hemisphere in adults and the cerebellum in childhood. In either location the tumor is a slow-growing, usually extensively invading growth, replacing normal glial tissue. Growth in the cerebellum frequently results in the formation of a cyst of varying size The cyst is smooth, glistening, with friable lining, and contains a light or dark brown fluid having a high protein content. It has been stated by Bailey[14] that this fluid is the product of transudation from the blood stream Tumor tissue exists in the wall of the cyst, usually localized in a mass, recognized as a mural node. The removal of the nodule, which varies in size, is the goal of the operation. Such cerebellar cysts usually involve a cerebellar lobe and extend to the midline and may reach a remarkable size before acute distress occurs. When obstruction of the fourth ventricle occurs the increased intracranial pressure may be acute and rapidly progressive

Supratentorial astrocytomas have often been silent growths over a period of years rather than months. Although cystic formations may occur in this




1. Occipital lobectomy.
   a. Midline exposed, vein coagulated.
   b. Cutting current for incision of brain.
   c. Further incision
2. Lobe removed.
   a. Lateral sinus and tentorium.
   b Sagittal sinus and falx
3. Scalp incision and extent of lobectomy.

relatively avascular type of lesion, such cysts are small in size and may be multiple. Calcification may be present and be visible by roentgen studies. The area of the hemispheric involvement may be difficult to identify grossly, since encapsulation does not occur. Demarcation develops more in the fibrillary type which is a more solid, granular tumor of grayish appearance. The protoplasmic type is softer and less distinguishable than the fibrillary type, which may offer a definite resistance or firmness of the tissue to the palpating fingertip. Such hemispheric lesions are eventually fatal although survival after operation may be for as long a period as three to ten years. The cystic cerebellar astrocytoma offers the prospect of a cure if completely removed. A more malignant type is the astroblastoma identifiable only by microscopic means and usually not diagnosed by its gross appearance.

A radical attack upon the hemispheric astrocytoma may include the employment of lobectomy if possible. At the time of exposure the hemisphere may be swollen by tumor tissue and its secondary effects. An internal decompression may be necessary for survival. The mid-hemispheric deep lesions which involve the corpus callosum are inoperable lesions.

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## *The Dura Mater*

The cranial dura mater is made up of white fibers and yellow elastic tissue It lines the interior of the skull as the internal periosteal layer of the bones, while at the same time it acts as a membrane for the protection of the brain It consists of two layers, the endosteal or the periosteal layer for the inner surface of the skull and the meningeal layer which is in juxtaposition to the cranial contents. These two layers are intimately connected except where they separate in the formation of the venous sinuses. The endosteal layer becomes continuous with the periosteal lining of the various foramina at the base of the skull; therefore, it is continuous with the pericranium or the external surface of the skull. Around the foramen magnum, the endosteal layer becomes adherent to the bone. The meningeal layer becomes continuous with the dura mater of the spinal canal. Certain dural projections extend into the cranial cavity These projections are made by the reduplication of the meningeal layer of the dura. These are cerebral falx, the cerebellar tentorium, the cerebellar falx and the sellar diaphragm.

The arteries of the dura mater have already been discussed on page 18 The veins anastomose with the diploic veins and also end in the various venous sinuses. Some meningeal veins form venous lacunae which in turn empty into the venous sinuses. Many such venous lacunae are noted near the midline in the middle portion of the superior sagittal sinus. They also are found near the transverse and straight sinuses. Arachnoid granulations extending into venous lacunae are present, particularly along the superior sagittal sinus The lacunae communicate with the underlying cerebral veins as well as diploic and emissary veins.

## Glioblastoma (Spongioblastoma Multiforme)

The commonest brain tumor is the spongioblastoma multiforme, comprising about fifty per cent of all the glial tumors. Virchow described these tumors in 1864. He characterized them as "slow-growing, infiltrating, fairly vascular masses in which hemorrhage occurs resulting in softening and cyst formation". This was the first type of brain tumor operated upon in the modern era by Godlee in 1884.

The glioblastoma occurs more commonly in males than in females by about three to one. It is a tumor occurring mainly in the fourth decade. Arising from the white matter it grows rapidly, usually producing death in one year after the onset of its clinical manifestations. Although it usually invades the white matter of the cerebrum it is occasionally found in the brain stem. Its boundaries are indistinct and its color variations are due to necrosis and hemorrhage within the tumor. Any portion of the brain may be involved by this common neoplasm which grows by infiltration, and frequently spreads along large nerve fiber tracts and the corpus callosum.

Growth beneath the surface produces characteristic gross features which may be identified. The deep-seated glioblastoma results in a swollen hemisphere with flattened convolutions and obliterated sulci. Palpation of the surface with the fingertip may be unrevealing. By means of a brain cannula tumor tissue may be identified by its firmness and difference in texture. The neighborhood may consist of soft, disintegrated brain substance easily aspirated into a syringe via the palpating cannula.

Surface extensions of the tumor allow identification by color, texture, and vascularity. Although some of these neoplasms are circumscribed to a lobe, most are not. At times they present single or multiple cysts. A cyst lends itself to the type of management illustrated.

Since complete extirpation offers the only means of cure, lobectomy, when the mass is localized to a lobe, may be indicated in the right-sided growths A biopsy is usually a disheartening and futile gesture, although indicated when lobectomy would profoundly disrupt function.

A cystic tumor above the tentorium is usually malignant. The commonest cystic tumor is the glioblastoma, although cystic formations occur in astrocytomas, metastatic tumors, and even meningiomas. Inspection of the interior of the cystic cavity may determine the advisability of excision of a mural nodule such as occurs in the cystic astrocytoma. In many instances a frozen section biopsy of the specimen is indicated at operation in order to determine the extent of the surgical excision.



In *1* a bone flap has been turned exposing the right temporoparietal region. A cystic tumor has been identified and verified by tapping with a ventricular needle. Xanthochromic fluid is aspirated from the cyst. The cyst cavity is then uncapped by excising a circular area of cortex at the most fluctuant and thinnest region overlying the tumor. The vessels are first coagulated or clipped. With the use of the electrocautery cutting unit a circular portion of the brain, about two inches in diameter, is removed. The cavity of the cyst is entered and the soft, membranous debris sucked away. Some vessels caught in the sucker may be coagulated by the electrocautery unit as shown in *c*.

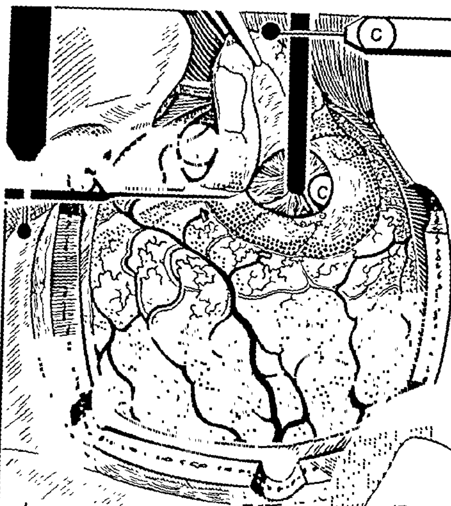
In *2* the position of the bone flap is shown, with a representation of the above procedure, as well as the area of the uncapping of the brain and the extent of the cystic cavity beyond the opening in the cortex.

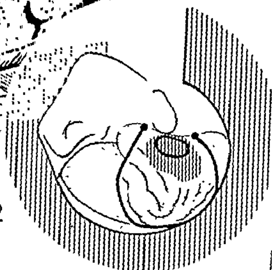
*No. 3* shows in greater detail the uncapped portion of the cyst, the body of which rather extensively undermines the cortex. The opening into the cystic cavity is well beyond the middle cerebral and temporal group of arteries. After uncapping, the cavity of the cyst is carefully inspected with a lighted retractor.

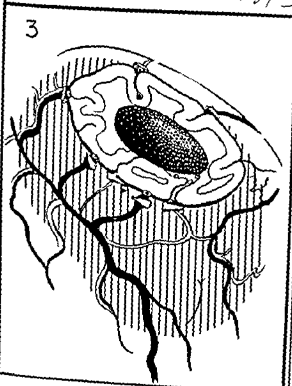
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*The Striatum*

The striatum consists of the caudate and the lentiform nuclei which join together anteriorly. The lentiform nucleus is made up of the putamen and the globus pallidus. The caudate is an elongated structure which forms the lateral boundary of the lateral ventricle and extends into the inferior horn of the lateral ventricle terminating in the amygdaloid complex. Between the caudate and the lentiform on the one hand, and the lentiform and the thalamus on the other, pass many fibers which constitute the internal capsule. The head of the caudate can be seen as the gray mass in the lateral aspect of the anterior horn of the lateral ventricle. It has been excised for certain extrapyramidal diseases. The putamen and the globus pallidus which are lateral to the internal capsule, are inaccessible neurosurgically, but experimentally, section of the ansa lenticularis has been accomplished for certain extrapyramidal diseases The amygdaloid complex is at the anterior end of the roof of the inferior horn of the lateral ventricle and this complex is also being excised in experimental neurosurgery.




1. Excision of cortex overlying tumor.
 a. Vessel doubly clipped and cut.
 b. Electro-surgical section
 c. Suction and coagulating current.

2. Position of skin incision and bone flap.
 Solid oval line—area of uncapping.
 Shaded area—extent of tumor.

3. The cavity of the tumor.
Shaded area—undermined cortex.

The sphenoid ridge divides the frontal from the temporal fossa, extending from the anterior clinoid process of the sella turcica laterally to the pterion. A meningioma of the sphenoid ridge may develop on the inner, middle or outer portion of the ridge.

Growths at the inner portion involve contiguous structures, including the optic chiasm, orbit, orbital fissures, cavernous sinus, and carotid artery. Removal of such a tumor is therefore hazardous. The proximity to the hypothalamus adds a danger resulting from the manipulation. Intratumoral piece-meal removal is feasible, but difficult, and usually incomplete.

The tumors of the middle portion of the sphenoid ridge offer greater chance of safe and complete removal. Usually these masses are larger, since growth is more silent than those on the inner portion of the wing. Expansion may occur into the frontal or temporal fossae. After resection of the frontal pole this tumor may be removed most easily by piece-meal excision.

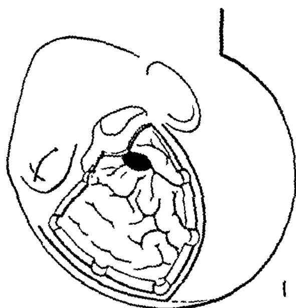
Outer sphenoid ridge meningiomas present a plaque-like growth with extensive hyperostosis of the adjacent bone which is even visible externally, and is always delineated in roentgen studies. When the dura is adherent to the tumor it should be excised with the tumor mass. Cauterization of the adjacent bone may also be of help in destroying remaining tumor cells in the bone. The mass may also be global without bone involvement, growing upward into the Sylvian fissure. This type of tumor is readily dissectable but care must be taken to avoid the Sylvian vessels. The extent of the tumor mass can be felt with the tip of the index finger and depending upon the mobility of the tumor mass it may be removed en masse. The tumor en plaque has to be removed piece-meal, if possible, including the area of dural and bone involvement.

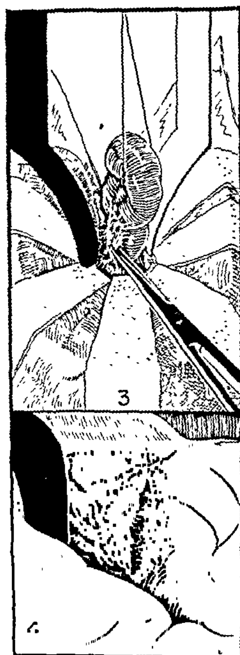
In *1* the position of the skin and bone flap are shown, as well as the position of an outer sphenoid ridge spherical mass and the frontal and temporal portions of the hemisphere.

In *2* the bone flap has been turned, the dura has been opened in a semicircular fashion. The dural flap has been sutured to the temporal muscle. The tumor at the junction of the frontal and temporal lobe has been identified and with care, the brain has been retracted from the tumor by the interposition of cottonoid strips. Gradual dissection of the tumor from the brain with cottonoid gives exposure. If the tumor mass is large, preliminary fractional removal of it may be done with the electrosurgical loop. The attachments of the tumor may be felt with the exploring index finger. In this instance, there was attachment of the tumor to the dura along the sphenoid ridge.

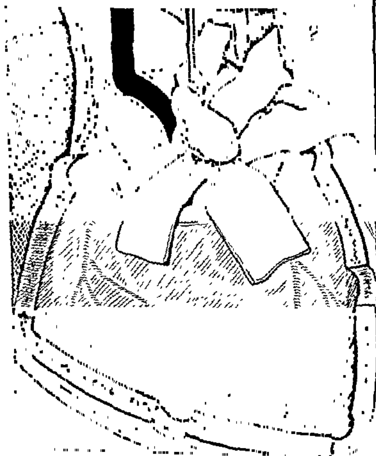
In *3* the tumor has been mobilized and its medial extent has been reached. With the aid of scissors the connection between the tumor and the dura is separated

In *4* the site of the tumor is shown after removal along the sphenoid ridge. The area of the attachment of the tumor should be cauterized with the electrocautery unit after excision of the involved dura





1. Bone flap and sphenoid ridge tumor.
2. Dura opened. Tumor separated from fronto-temporal cortex.
3. Tumor exposed further and attachments separated.
4. [illegible]



## The Pituitary Gland

The pituitary gland lies in the pituitary fossa and weighs about half a gram. It is connected to the hypothalamus by the pituitary stalk. The pituitary body is immediately under the dural fold called the diaphragma sellae. The stalk passes through a circular opening in the dural diaphragm. The pituitary body consists of the anterior lobe, the posterior lobe and the tuberal portion. The tuberal portion is immediately around the pituitary stalk at the base of the brain and is partly suprasellar. The posterior lobe of the hypophysis may be divided into an intermediate lobe and the neural lobe, or the so-called neural hypophysis. The anterior lobe is pinkish or reddish in color, while the posterior lobe is gray.

The pituitary body arises from an outpouching of the ventral part of the brain uniting with a dorsal outpouching of oral mucosal lining. The latter is also called the Rathke's pouch. The anterior lobe of the adult pituitary body arises from the oral outpouching or the Rathke's pouch, whereas, the posterior lobe has its origin in the outpouching of the base of the brain in the hypothalamic area. The remnants of Rathke's pouch may be present in the posterior nasal pharynx and the body of the sphenoid

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*The Sphenoid Bone*

The body of the sphenoid contains the pituitary fossa and the sphenoid sinuses. Its two wings are the lesser and the greater wing The lesser wing forms the posterior border of the anterior fossa and terminates medially in the anterior clinoid process. The greater wing is a portion of the middle fossa and contains the foramen spinosum, the foramen ovale, the carotid sulcus, the foramen rotundum, and the superior and inferior orbital fissures. The optic foramen, the anterior, middle and posterior clinoid processes, as well as the dorsum sellae are all portions of the sphenoid bone Anteriorly, the sphenoid bone connects with the orbital plate of the frontal and the perpendicular portion of the ethmoid, to form the anterior fossa. Laterally, it unites with the temporal bone and the petrous portion of the temporal bone to form the middle fossa, and posteriorly, it is joined by the basilar process of the occipital to help form the posterior fossa. The greater wing of the sphenoid also joins with the frontal and zygomatic bones to help form the orbital boundary. The inferior aspect of the sphenoid bone does not concern us, except that the pterygoid processes, one on either side of the midline are important structures, as the lateral pterygoid plate at times may be large enough to make injection of the third division of the trigeminal an impossibility

bone. The tuberal portion around the stalk, as well as the so-called pars intermedia arise from the oral evagination.

Pituitary tumors arise from cells in the anterior lobe near the stalk. These result in chromophile, chromophobe or mixed adenomas of the pituitary. Tumors also may arise from remnants of Rathke's pouch. These form the craniopharyngiomas.

In the anterior lobe, one normally finds chromophile cells which stain intensely. These may be eosinophilic or alpha cells, or basophilic or beta cells. The chromophobe cells do not contain heavily staining granules and they constitute about half of the cells in the anterior lobe. About a tenth of cells are the so-called basophilic cells and 40 per cent are eosinophilic cells according to Bailey. The posterior lobe contains neuroglial cells and so-called pituicytes.

Pituitary adenomas usually are made up of chromophobe cells arising most commonly in the tuberal part of the pituitary near the stalk. So-called basophilic adenomas are microscopic lesions and the basophilism of Cushing is a polyglandular syndrome involving pituitary, thyroid, adrenal and possibly also parathyroid glands. Chromophile adenomas are mainly characterized by eosinophilic cells which have fine granules staining red with eosin. There may be mixed tumors consisting of chromophobe and chromophile cells. Pituitary adenomas may undergo necrosis with the formation of cystic cavities. Others remain solid having a brownish, reddish color

Craniopharyngiomas usually occur in young adults and children, although they may also be seen in later life. Craniopharyngiomas usually arise from remnants of the Rathke's pouch, these remnants usually occurring in the region of the stalk and in the anterosuperior portion of the anterior lobe. Consequently in the majority of cases, craniopharyngiomas occur in a suprasellar position. These tumors may vary from a solid circumscribed mass to large multilocular cysts with a gray capsule containing yellow, or brown, or greenish-brown fluid, with cholesterol crystals and areas of calcification which show in the roentgenogram either as islands of calcification or a thin calcifying border about the entire tumor. Microscopically, these tumors are lined with squamous cells or ciliated columnar cells, or they may resemble the enamel pulp of developing teeth. They are also called adamantinomas and frequently may be rapidly growing and malignant.

### Optic Nerve, Chiasm, Tract and Radiation

The optic nerve extends back from the posterior aspect of the eyeball as the continuation of the retinal lining. Its outer covering is continuous with the endosteal layer of the dura. Immediately under the outer sheath of the optic nerve is an arachnoid remnant and a subarachnoid cavity which is continuous with the subarachnoid cavity of the brain. Thus increase in intracranial pressure may influence the optic nerve head. The

optic nerve enters the cranial cavity through the optic foramen in company with the ophthalmic artery. The optic nerves join over the dorsum sellae to form the optic chiasm. Immediately lateral to the optic chiasm and nerve is the internal carotid artery. Posterior to the chiasm the optic tract extends to the lateral geniculate body. From here the fibers arise to form the optic radiation. These fibers on their way toward the occipital pole of the hemisphere and the calcarine cortex, loop slightly forward into the temporal lobe. These forward looping fibers are quite definite in some specimens; in others they are not. An involvement of the posterior medial portion of the temporal lobe thus may invade these looping fibers with resultant homonymous hemianopia.

The optic nerve near the chiasm contains some fibers from the nasal retina on the opposite side which actually loop forward into the nerve and then posteriorly to form the optic tract. These looping fibers may be damaged in involvement of the optic nerve near the chiasm or just rostral to the chiasm with resultant blindness in the homolateral eye and varying degrees of temporal field defect in the opposite eye. Chiasmal involvement results in a bitemporal hemianopia and optic tract, optic radiation as well as occipital cortex disease results in homonymous hemianopia. The type of field defects with cortical involvement has already been discussed under the pathophysiology of the cerebral cortex.

## Surgery of the Pituitary Gland—Historical

The former transsphenoidal approach to the pituitary gland has been replaced with a transfrontal craniotomy because of the recognized advantages of the latter exposure.

A temporal route for operations upon the pituitary gland was first suggested by Horsley[231], which was the result of his experimental procedures. Horsley performed operations by the temporal route but the details of his results were never published although nine operations were done. One operation employed the use of a frontal intradural approach; this operation being done in 1889. Cushing[91] also used the temporal route with unsatisfactory results. The intracranial approach to the pituitary gland did not win favor in spite of the pioneering efforts by Horsley.

Schloffer first suggested reaching the pituitary by way of the nasal route or transsphenoidal extracranial approach. This was an extensive and mutilating operation (first done in 1907) requiring displacement of the nose in order to gain ingress through the anterior wall of the sphenoidal sinus and the anterior wall of the sella turcica. Modifications of this extracranial approach were made by Kanavel, von Eiselberg, Kocher[264] and Halsted. These modifications led to the perfected technique practiced by Hirsch and Cushing,[91] who, in 1910, each used the same method on the same day for the first time Cystic tumors could be readily evacuated by this procedure When the tumor was solid the operation was considered a sellar decompression Doing the operation in two stages Hirsch used local anes-

thesia, while Cushing used intratracheal ether. Cushing, using the inferior nasal submucous route, had a mortality rate of nine per cent.

In spite of the success of the extracranial approach, and the low mortality, its disadvantages were recognized, particularly when the solid tumors were encountered. A return to the intracranial approach via a frontal route was stimulated by the reports of Frazier[151], who reported his procedure in 1913. By Frazier's method a frontal craniotomy flap was made with an incision to expose the supra-orbital ridge. The supra-orbital ridge was divided and this wedge of bone displaced, allowing the roof of the orbit to be resected. The dura was incised at a point where the optic nerve was seen leaving the cranial cavity. The pituitary region was then brought into view. Gradually, modifications were introduced, notably those of Heuer in 1918, who employed a large frontoparietal osteoplastic flap. A reduction in the size of the flap was suggested by Dandy[105], and others have found this approach satisfactory.

X-ray therapy which was employed in the early part of the 20th century for treatment of pituitary tumors has established itself as a useful form of therapy. Deep x-ray treatment may be used preoperatively as trial therapy. If no improvement occurs in a period of from six to eight weeks after the beginning of the therapy, then surgical treatment should be recommended.

Although the pituitary adenoma is the commonest lesion approached by a transfrontal procedure, other chiasmal lesions may be attacked, including aneurysms, tumors of the optic nerves, arachnoiditic abnormalities, craniopharyngioma, and a dilated third ventricle for ventriculostomy. Decompression of the orbit is accomplished by this type of approach.

The chromophobe adenoma is the commonest pituitary tumor arising from the chromophobe cells of the anterior lobe. The other tumor derivatives occur from the less common eosinophilic or basophilic cells. By its growth the chromophobe tumor produces compression and arrest of the secreting cells, contrary to the hypersecreting eosinophilic or basophilic neoplasms. One-quarter of the chromophobe adenomas are cystic. The majority, if not cystic, are soft and readily removed by suction after incision of the capsule. The contents are first removed, followed by partial removal of the capsule, which procedure has been compared to a "subtotal thyroidectomy" by Dandy.[116]

Infrequently it may be necessary to section an optic nerve for exposure of an intrasellar lesion. A frontal lobectomy is rarely required. Caution must be taken to avoid cerebral and vascular damage by retraction of the hemisphere, or the carotid and anterior communicating arteries.

Although typically the chromophobe adenoma is associated with an enlarged pituitary fossa and bitemporal field defects, in some instances the tumor may grow mainly on the outside of the pituitary fossa with a normal bony structure in this region. Under these circumstances the tumor mass may compress the optic tract further posteriorly with this extrasellar growth

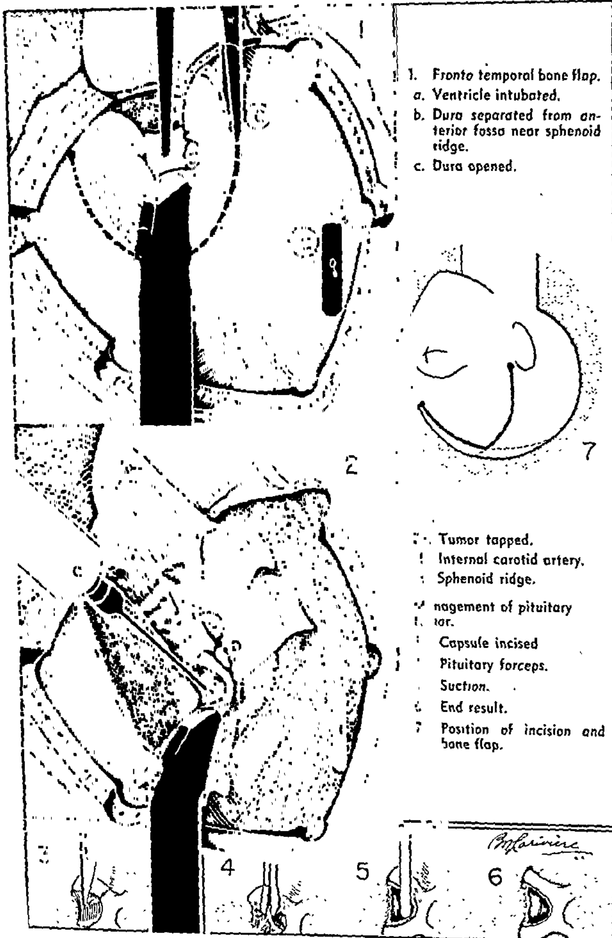
extrasellar extension should be considered

ons in this neighborhood.



At *7* the position of the frontal incision is shown. The bone flap is a *frontotemporal flap made on the right side, if possible. The base of the* bone flap lies at the sphenoid junction in order to have direct access to the base of the skull at the anterior fossa. The frontal sinus is avoided. At *a*, in *1*, a brain cannula is first inserted into the ipsilateral ventricle. Before much cerebrospinal fluid escapes the cannula is replaced with one of the flanged type of appropriate length which remains in situ for the purpose of decompression. At *b* the dura is separated from the base of the anterior fossa along the sphenoid ridge. This is extended toward the pituitary fossa. After the dura has been mobilized as far medially as possible it may be incised in a linear or semicircular fashion as shown in *c*. The dural flap is now stitched to the temporal muscle in the intradural type of exposure. The frontal lobe with its junction at the temporal lobe is elevated along the sphenoid ridge until the pituitary region is exposed, as shown in *2*. The sphenoid ridge is followed until it ends at the anterior clinoid process and the optic nerve. Evacuation of the cisterna chiasmatis allows more exposure. With careful *retraction over cottonoid, the optic nerve, the carotid artery, the chiasm,* and the optic nerve on the opposite side are brought into view. Lighted retractors are extremely valuable in this exposure. The pituitary adenoma is usually of a bluish-gray color. An 18-gauge needle is inserted into the mass between the two optic nerves. The presence of a cyst with dark yellow or brown fluid may be ascertained. Preliminary needling of any mass in this region is always made a first step to exclude the presence of an aneurysm.

In *3* the incision of the dorsal portion of the pituitary adenoma is made with a sharp-ended knife. In *4* pituitary forceps are used to enter the cavity of the adenoma for removal of the tissue. In *5* the adenoma, particularly if cystic, is sucked away with a suction tip It is important to introduce the suction tip with a thumb removed from the opening on the handle of the instrument This maintains a low suction pressure, avoiding injury to the optic nerves and vessels. Upon evacuation of the mass the optic nerves become relaxed. A subtotal capsular excision completes the procedure. *Gelfoam® may be useful as a temporary compress in the bed of the solid tumor* which is initially gently applied and carefully removed before closure. Wound closure is made as previously described. The dura is sutured allowing room for a thin flat gutta-percha drain. Careful attention must be given to hemostasis.


1
2
4
5
6
7
1. Fronto temporal bone flap.
a. Ventricle intubated.
b. Dura separated from anterior fossa near sphenoid ridge.
c. Dura opened.
Tumor tapped.
Internal carotid artery.
Sphenoid ridge.
nagement of pituitary
tor.
Capsule incised
Pituitary forceps.
Suction.
End result.
Position of incision and bone flap.

In some patients with obstructive internal hydrocephalus due to adhesive *arachnoiditis about the fourth ventricle, and the foramina of Luschka and* Magendie, a third ventriculostomy may be the procedure elected for by-passing the obstruction.

In *1* the position of the skin incision and that of the bone flap is *shown.* An adequate frontotemporal bone flap is required for exposure of the neighborhood of the third ventricle.

As shown in *2* the dura has been opened with the base toward the sphenoid ridge. It is important to have sufficient bone removed immediately under the temporal muscle to give adequate access to the base of the skull at the junction of the anterior and middle fossae. The brain is gently elevated along the lesser wing of the sphenoid, until the bulging third ventricle pre-*sents immediately over the optic nerve and chiasm. Complete decompression* of the lateral ventricle is avoided to maintain a bulging of the third ventricle with cerebrospinal fluid. Under these circumstances a small opening into the ventricular wall is made and enlarged with the scissors. Such an opening remains patent for many months, and in some cases, for years. Scarff also suggests the use of a fistulous opening through the floor of the third ventricle into the interpeduncular cistern. This is accomplished by using a specially constructed hook which is introduced through the opening made in the wall of the ventricle above the chiasm and bluntly making an opening *in the floor of the third ventricle into the interpeduncular cistern.*

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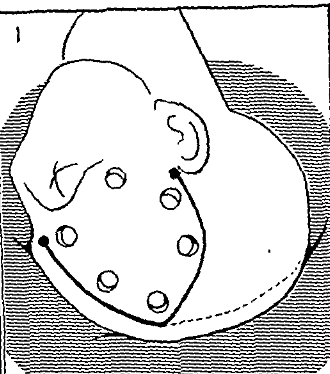
### *The Lamina Terminalis*

The lamina terminalis forms a portion of the anterior boundary of the *third ventricle There is a thin layer of gray matter* which extends from above the optic chiasm to the rostrum of the corpus callosum. In patients with enlarged third ventricles, this portion of the anterior wall may be dilated This is the area where a third ventriculostomy may be performed by wide incision. Other structures that form the anterior boundary of the third ventricle, above the lamina terminalis, are the columns of the fornix and the anterior commissure. The interventricular foramen or the foramen of Monro is found between the thalamus, laterally, and the thalamus posteriorly, and the column of fornix anteriorly A certain number of patients have a massa intermedia which crosses from one thalamus to *the other and thus breaks the continuity* of the third ventricular cavity The massa intermedia, as well as the impression of the anterior commissure, may be seen in many well-filled third ventricles in air studies. In some cases, one may also be able to see the posterior commissure at the posterior-superior border of the third ventricular cavity.

Third Ventriculostomy.

1. Position of incision and bone flap.

2 Dura opened.
Brain retracted along lesser wing of sphenoid a.
Cystic third ventricle visualized and widely incised.




2



Historically, intra-orbital tumors have been within the province of the ophthalmologist and they have been attacked directly by removal of the orbital contents or by an indirect approach such as that suggested by Krönlein in 1887, which was a lateral approach to the orbit. Certain disadvantages involve both procedures. The limitation of the exposure when there was an intracranial extension or projection of the orbital mass was apparent. The need for an intracranial procedure which could completely remove the lesion also became evident. In 1922 Dandy[97] reported the advantage of an intracranial operation with removal of the orbital roof. Later, ophthalmologists and neurosurgeons, working together in the management of orbital tumors, found this cooperation highly satisfactory. It is of note that pulsation of the globe, following decompression of the orbital roof, has not been observed following this operation.

Orbital decompression also has been employed for treatment of malignant exophthalmos in order to preserve both the optic nerve and the globe from irreparable damage. This was suggested by Naffziger and Jones[321] in 1932, and has often been termed the "Naffziger procedure".

In *1* the incision in the scalp and the bone flap opening are shown. A coronal incision may be preferred. A low bone flap is adequate for this purpose. The exposure must be sufficiently inferior to reach conveniently the floor of the anterior fossa.

In *2* the bone flap has been turned. The temporofrontal junction has been rongeured away to the border of the anterior fossa. The dura is then separated from the floor of the anterior fossa by cottonoid dissection. The dura need not be opened. A chisel is used to chip the thin orbital roof. A small opening is made. This is enlarged with the use of a rongeur or a Kerrison bone cutter. The opening in the roof is extended in all directions until an adequate exposure has been obtained. The sphenoidal and ethmoidal sinuses are avoided.

As shown in *3* the use of a Kerrison rongeur is helpful in this connection. Posteriorly, bone should be removed to the superior orbital fissure The optic foramen may also be unroofed. A wide lateral removal is also desirable. A crucial incision avoiding the supra-orbital nerve is now made in the orbital capsule and the contents of the orbital cavity are exposed. This would complete the steps necessary for unroofing of the orbit in exophthalmos. In *4* and *5* a tumor in the orbit, lying behind the globe, can be manipulated by this approach. In *4* a meningioma is removed. Such a tumor is carefully separated from the surrounding tissues and excised. In *5* the tumor bed, the lacrimal gland anterolaterally, the superior obliquus, the superior rectus and the levator palpebrae medially are seen. Care is taken not to injure these muscles during the excision of the tumor It should be noted that brain swelling may temporarily increase the degree of proptosis, and eye protection is needed postoperatively.

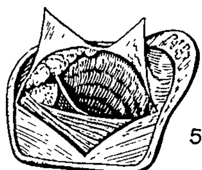
1. Position of incision and craniotomy. (A coronal incision may be preferred.)

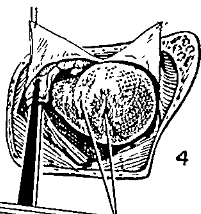
2. Anterior fossa floor exposed. Chisel used to begin opening.

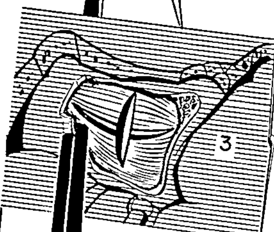
3. Wider removal of the floor. Use of Kerrison rongeur recommended.

4 Endothelioma above and behind eyeball exposed and removed.

5. Lacrimal gland, eyeball, eye muscles after enucleation of tumor.

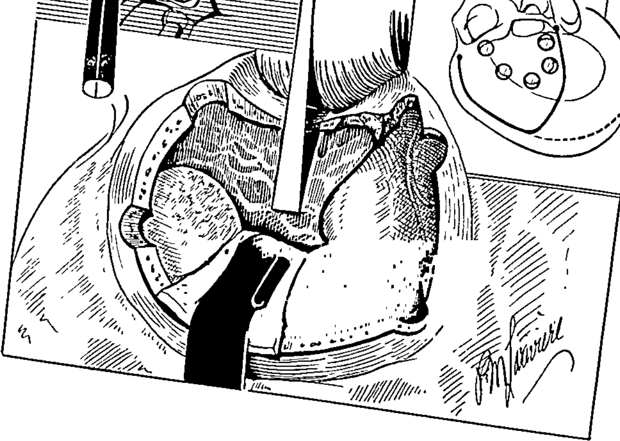








## Exposure of the anterior third of the corpus callosum and neighborhood ▶

Exposure of the anterior third of the corpus callosum may be employed for deep anterior midline tumors, neoplasms in the anterior portion of the third ventricle, and for vascular lesions in the anterior cerebral distribution. The anterior cerebral artery and the anterior communicating vessels can be easily viewed by this approach.

In *1* the position of the incision and the openings in the skull are shown. It is important to make the burr holes as near the midline as possible or past the midline on the opposite side. For exploration of an aneurysm of the anterior cerebral artery, it is better to cross the midline, using two burr holes on the opposite side of the sagittal sinus. Sinus bleeding in the anterior third is minimal and easily controllable. Exposure is much more adequate when it includes a portion of the skull past the sagittal sinus on the opposite side from that being explored.

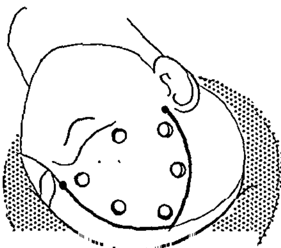
In *2* the bone flap is reflected. The dura has been opened. The brain has been carefully retracted following ligation of parasagittal veins extending into the sagittal sinus. The falx is shown and after careful retraction of the brain the anterior border of the corpus callosum is seen. A cerebral vein with a clip attached is shown in *a*. The anterior cerebral artery, just anterior and inferior to the anterior border of the corpus callosum is shown at *b*. Care must be taken to avoid injury to these vessels, particularly the left anterior cerebral artery. The proximal portion of a cut vein near the sagittal sinus with a clip attached to it is shown at *c*. At *d* a lighted retractor is placed immediately over the incision in the corpus callosum which is avascular and may be compressed or elevated by an underlying mass in the anterior third of the third ventricle.

Such an exposure may be aided by a preliminary ventricular tapping and aspiration of as much cerebrospinal fluid as necessary to relax the dura and the brain.

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### *The Diencephalon*

The diencephalon consists of: the thalamus; the hypothalamus and the mammillary bodies; the metathalamus which comprises the medial and lateral geniculate bodies; the epithalamus, which contains a habenula, the pineal body and the posterior commissure; and the subthalamus which contains the zona incerta and the corpus Luysi The diencephalic region, although extremely important functionally, is rarely accessible surgically



1. Osteoplastic craniotomy should extend to the midline.

2. Frontal lobe retracted laterally after cutting coagulated veins extending into the sagittal sinus.
   a. Midline vein clipped and cut.
   b. Anterior cerebral artery.
   c. Vein extending into sagittal sinus clipped.
   d. Corpus callosum incised.

## Exposure of the posterior portion of the corpus callosum and neighborhood ▶

The posterior portion of the corpus callosum may be exposed and sectioned for deep posterior midline and pineal tumors. This is done on the right side. It is known that direct surgical attack upon the pinealoma carries a high mortality. The preferable method of treatment is the employment of ventriculocisternal intubation to relieve the increased intracranial pressure, followed by irradiation therapy.

In *1* is shown the incision and the opening for exposure of the posterior portion of the corpus callosum. The drill holes are at or near the midline for easy access to the medial aspect of the hemisphere. The craniotomy opening is extended to near the superior nuchal line so as to mobilize the occipital pole of the hemisphere with ease.

In *2* the bone flap has been turned and the dura reflected. The occipital lobe has been retracted laterally. The posterior aspect of the corpus callosum is shown, as well as the falx at the midline. Venous communications from the cortical surface to the sagittal sinus require coagulation or the use of clips Such venous tributaries become richer as the middle third of the hemisphere is reached. Care must be taken to avoid tearing of the vessels after the operative field has been exposed.

*The corpus callosum may be thinned and elevated by an underlying mass.* Section of the corpus callosum is usually bloodless. Care is taken to avoid injuring the vein of Galen which is in the field, possibly dislocated from its usual posterior site by the position and size of the neoplasm.

Better exposure of the mass may be aided by section of the tentorium adjacent to the straight sinus when the mass has grown posteriorly. This allows for safer mobilization. Intracapsular enucleation is usually advisable with gradual traction and ultimately capsular removal of the tumor mass.

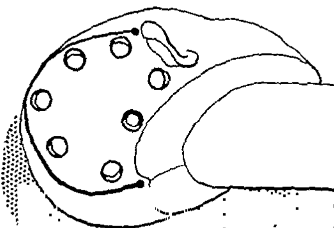
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*Corpus Callosum*

The corpus callosum is made up of commissural fibers between the two hemispheres. Its median portion forms the roof of the lateral and the third ventricle Anteriorly, it ends in the genu which inclines inferiorly and posteriorly in front of the septum pellucidum It terminates in the rostrum which becomes continuous with the lamina terminalis. Posteriorly the corpus callosum ends in the splenium. This is the thickest portion of the corpus callosum and it is immediately above and posterior to the pineal gland The fibers curving forward toward the frontal lobes at the genu constitute the forceps anterior and those at the splenium extending toward the occipital lobes make up the forceps posterior. Between these two, is the tapetum which consists of the fibers extending to the hemispheres laterally It is the fibers of the tapetum which form the roof of the body of the lateral ventricle on either side and the roof of the third ventricle.

1. Parieto-occipital craniotomy should extend to the midline.

2. Occipital lobe retracted away from midline after coagulation of cerebral veins extending into sinus.
   a. *Veins clipped and cut.*
   b. *Sagittal sinus.*
   c. *Tentorium cerebelli.*
   d. *Lighted retractor exposing corpus callosum.*





Tumors involving the lateral ventricles may grow to a large size before detection. Often they are circumscribed and slow growing, arising from the ependymal lining cells of the ventricle. They may be situated either well anteriorly or posteriorly. Infiltrating tumors may also obliterate the ventricles by expansion, the tumor bulging into the cavity of the ventricle. Tumors of the lateral ventricle may be benign and encapsulated or they may be invasive in type.

Tumors of the third ventricle include "colloid cysts", pineal tumors in the more posterior portions of the third ventricle, tumors which invade the third ventricle from the surrounding cerebral tissue, as well as tumors that extend upward into the third ventricle from the sellar and parasellar regions.

Cortical incisions, as illustrated, may be necessary to identify the type of lesion present. Lateral ventricle tumors and some of the third ventricle tumors may be attacked in this fashion. The larger masses are most easily handled by means of a lobectomy, either frontal or occipital. Attachment of the tumor mass to the choroid plexus requires clear and direct vision in order to obtain hemostasis when separating the vascular plexus from the tumor mass.

In *1* a diagram of the lateral ventricle in relationship to a cortical incision and the motor and sensory cortex is shown. The sensory cortex is shown at *a* and the motor strip is shown at *b*. At *c* an incision is made into the body of the lateral ventricle in the occipitoparietal area. At *d* an incision is shown in the anterior portion of the ventricle in the frontal area. It is to be noted that the parieto-occipital incision is in a supero-inferior direction, with the line of incision extending downward and forward. In the frontal region the incision is parallel to the frontal convolutions projecting in an anteroposterior direction

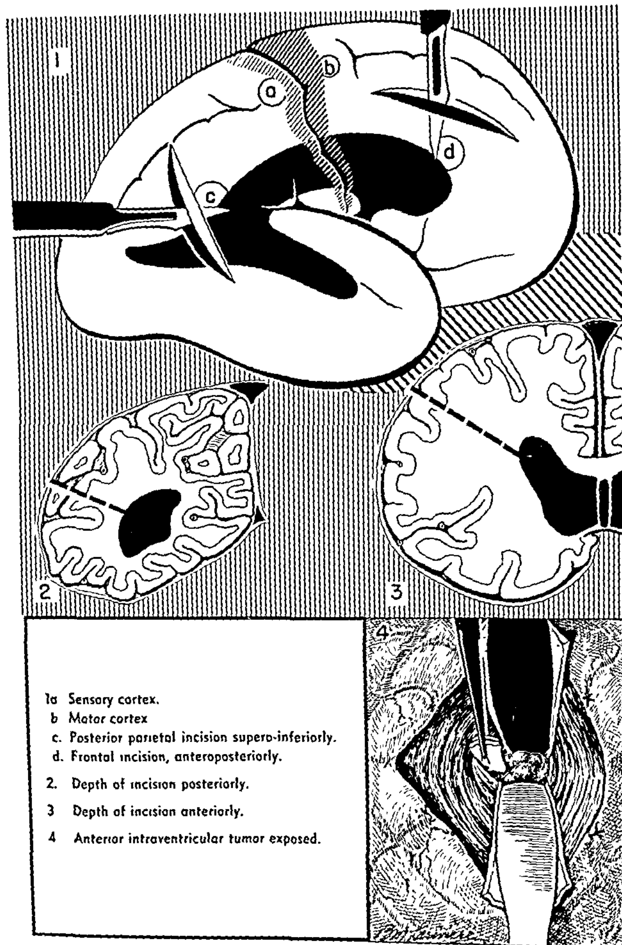
In *2* and *3* cross-sections of the brain and lateral ventricle in the parieto-occipital area and in the frontal region show the relative depth of the incision required to reach the ventricle.

In *4* exposure of a tumor in the lateral ventricle through a parietooccipital incision is shown After biopsy and judgment as to prospect for enucleation, the decision for a lobectomy mav be made.

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### *The Pineal Gland*

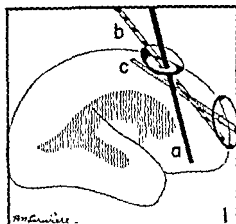
The pineal gland is a globular mass a little less than 1 cm. in length. It is found between the superior colliculi. It is attached to the posterior superior border of the roof of the third ventricle. Tumors of this gland may be associated with *sexual precocity, hypertrichosis, hypergenitalism* in young males. Other signs are due to neighborhood involvement, mainly characterized by paralysis of upward gaze and convergence The pineal gland is calcified and may be seen in roentgenograms in 50% of adult skulls



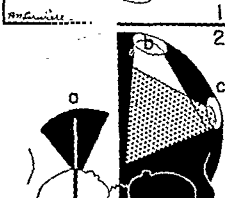

1a Sensory cortex.
b Motor cortex
c. Posterior parietal incision supero-inferiorly.
d. Frontal incision, anteroposteriorly.
2. Depth of incision posteriorly.
3 Depth of incision anteriorly.
4 Anterior intraventricular tumor exposed.

In 1934, Moniz described his now well known operative procedure called *lobotomy*. There have been many variations of the technique, including those of Freeman and Watts, Poppen, Lyerly and others; excision of the cortex from a portion of the superior and medial surface of the frontal lobe or topectomy (Pool); the so-called icepick operation of introducing a sharp instrument through the roof of the orbit, just under the brow and inserting it into the base of the brain for 5 cm. and stroking the instrument from side to side, sectioning the frontal white matter at the base; and finally, undercutting of the frontal cortex, described by Scoville. These various procedures are shown in *1* to *6*. *1*, at *a*, is the classical lobotomy, immediately in front of the rostral portion of the ventricle; *b* and *c* are methods for undercutting, either anteroposteriorly or postero-anteriorly through trephine openings. In *2* the superior approach and the lateral approach are shown at *b* and *c* and the icepick approach is shown at *a*. In *3*, through a frontal osteoplastic craniotomy the burr openings of which are outlined in *4*, the frontal cortex is exposed and a portion of the superior frontal convolution, including the convolution on the medial aspect of the hemisphere, is excised on either side of the sagittal sinus.

The classical procedure of lobotomy is shown in *4*, *5* and *6*. This procedure may be done on one or both sides. The unilateral procedure has been effective in stopping pain in some cases of intractable pain due to cancer. Evidence is accumulating that the section of fibers of the frontal lobe, medial to the anterior end of the ventricle, are those most important for relief of pain. The more lateral and inferior fibers are those which mediate the undesirable personality defects seen in the classical lobotomy. As shown in *4*, a button of bone is removed from the frontal area about 1 inch to 1½ inches in diameter. The center of this button of bone is 3½ cm. in front of the coronal suture, and 3½ cm. from the midline. The coronal suture parallels a line drawn from anterior ear to anterior ear, extending over the vertex. In *5*, at *a* a circular saw is shown to obtain the button of bone which has been removed in the figure immediately to the right. Here, the dura has been incised crucially, and the edges of the dura are seared to the edge of the bone by electrocautery. All bleeding points are completely controlled. In *6*, at *a* a ventricular needle is inserted to note the position of the ventricle. If the ventricle is entered the needle is reintroduced somewhat more rostral, until one is sure that one is in front of the ventricle. In some cases with large ventricles the incision of the white matter of the frontal lobe, 3½ cm. in front of the coronal line, is satisfactory even though the ventricle is entered. In *b*, is shown the leucotome which is a blunt, spatula-like instrument. It is introduced into the brain after the surface vessels have been coagulated and the surface of the brain has been incised from side to side, with the electrocautery unit. The leucotome is now inserted to a depth of 5 to 6 cm and with great care, and making sure that the plane of the section remains

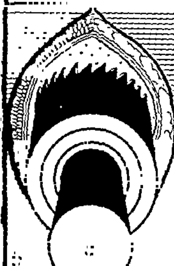


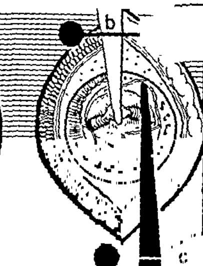

1a. Lobotomy just in front of ventricle.
b, c. Undercutting of frontal lobe.
2a. "Icepick" operation.
b. Lobotomy by the superior approach.
c. Lobotomy by the lateral approach.
3. Topectomy
a, b. Area of brain excised including superior frontal convolution and medial surface of hemisphere.
4. Trephine opening made 3½ cm. in front of coronal suture and 3½ cm. lateral to midline.
5a. Circular saw removing button of bone.
b, c. Dura opened and seared to bone edge.
6a. Ventricular needle inserted in front of lateral ventricle.
b. Leucotome cutting from depth of 6 cm.

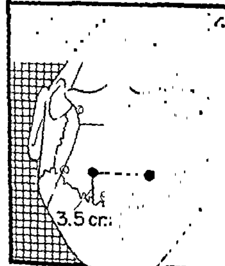


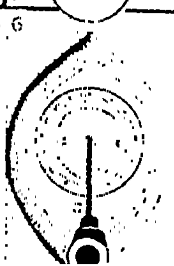


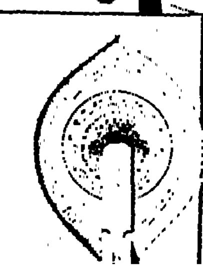






constant, the instrument is stroked medially and laterally. Also, one extends the section of the medial aspect of the hemisphere until one is sure that the medial fibers have been well cut. It is important to control undue bleeding. A lipiodol®-soaked sheet of gelfoam® is now placed in the incision of the brain. Postoperative bleeding may be seen if some opaque substance has been introduced into the area of section; if the position of the opaque substance changes due to the presence of an enlarging blood clot, a diagnosis may be made on x-ray of the skull alone.

An opening, $1\frac{1}{2}$ inches in size, is sufficiently large to use a fine suction tip and electrocautery for making the incision instead of the leucotome knife. In this way the bleeding points encountered can be coagulated and the possibility of postoperative bleeding is much less.

In those cases where a unilateral procedure has been used for the relief of intractable pain, if the painful condition continues, bilateral section may be more successful. In many instances of this type we have begun with a unilateral procedure and eventually made a section on the opposite side as well. We have used the right side first in most of these patients.

Following completion of the procedure a very thin layer of gelfoam® may be applied over the brain. The button of bone is replaced and the skin is closed in layers. The use of the circular saw minimizes skull defects in these patients. It is preferred to burr openings by a Hudson drill.

## Open and Closed Carotid Angiography and Internal Common Carotid Ligation

### Anatomical and Physiological Considerations of Neck Structures

*The Digastric Muscle* The digastricus is posteriorly attached to the mastoid notch of the temporal bone. Anteriorly it arises from the internal surface of the lower border of the mandible near the midline. These two portions or the so-called posterior and anterior belly of the digastricus, join in a tendinous connection which passes through the stylohyoid muscle in a fibrous loop on the greater wing of the hyoid bone. The posterior belly of the digastric muscle is in intimate relation with the facial nerve, which after its exit from the stylomastoid foramen extends toward the face on the belly of this muscle.

*The Carotid Sheath* The carotid sheath is an extension of the deep cervical fascia and encloses the carotid artery, the internal jugular vein and the vagus nerve. The carotid complex is in a medial and deep position compared with the jugular vein which is lateral and somewhat more anteriorly placed The vagus nerve is between the two vessels and posterior to both.

*The Common Carotid Artery.* The common carotid artery on the right side is given off from the innominate artery, while the left common carotid arises from the arch of the aorta The common carotid artery in the neck

passes up from behind the sternoclavicular articulation to the upper border of the thyroid cartilage. Here it divides into its external and internal branches. In the carotid sheath the internal jugular vein lies lateral to the artery and somewhat anterior to same, while the vagus nerve lies between the artery and the vein somewhat posterior to both vessels. These relationships should be remembered with due consideration given to the position of the neck during operative procedures when the neck is not in the anatomical position. Posterior to the structures in the carotid sheath are the transverse processes of the cervical vertebrae covered by the longus coli and the longus capitis muscles. The sympathetic trunk in the cervical region lies between the carotid artery and the prevertebral muscles. On its medial aspect the common carotid is in relation with the esophagus, the trachea, and the thyroid gland which covers a portion of the vessel in its middle third. Higher in the neck, the larynx and the pharynx are in a position medial to the artery. On the lateral aspect of the carotid sheath are the sternocleidomastoid and platysma muscles and lower down in the neck and somewhat more anteriorly placed are the structures which include the stylohyoid, the omohyoid, the sternohyoid, and the sternothyroid muscles. In the lowermost portion of the neck on the right side is the recurrent laryngeal nerve which crosses behind the common carotid artery.

*The Internal Carotid.* The internal carotid artery extends up from the bifurcation of the common carotid at the level of the upper border of the thyroid cartilage. It runs upward in front of the transverse processes of the upper three or four cervical vertebrae to the carotid canal in the temporal bone In its beginning it is quite superficial but as it extends up it lies behind and slightly laterally to external carotid artery. As it progresses upward it is under cover of the sternocleidomastoid muscle, platysma and the skin. Further up it passes under cover of the parotid gland and in this position it may be crossed by the hypoglossal nerve. A little higher it is separated from the external carotid by the styloglossus and stylopharyngeus muscles, the tip of the styloid process, the glossopharyngeal nerve and the stylohyoid ligament. Posteriorly it lies on the prevertebral fascia and the longus capitis muscle, as well as the superior cervical ganglion and the sympathetic trunk. Lateral to the internal carotid are the vagus nerve and the jugular vein, with the nerve somewhat posterior to the plane of the artery. At the base of the skull, the hypoglossal, the accessory, the vagus and glossopharyngeal nerves are found between the internal carotid artery and the internal jugular vein. The internal carotid artery extends up through the carotid canal of petrous bone and then it is contained in the cavernous sinus where it forms a semicircular course between the posterior and anterior clinoid processes, and then it enters the cranial cavity on the medial side of the anterior clinoid process; passing between the optic and the oculomotor nerves, it extends up into the anterior perforated substance and continues to the lateral cerebral fissure as the middle cerebral artery. The cavernous and the cerebral portions of the internal carotid artery form the syphon of the ca-

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rotid, a term which is in wide clinical usage. The carotid artery gives off two small twigs while it passes through the temporal bone. These are the caroticotympanic and the artery to the pterygoid canal. The cavernous portion gives off the ophthalmic, the anterior meningeal branch to the trigeminal ganglion and branches to the pituitary gland and the cavernous sinus neighborhood. In its cerebral portion the *anterior cerebral, the middle* cerebral, the posterior communicating and the choroidal vessels are given off.

*The Carotid Sinus.* A portion of the so-called carotid sinus is included in the proximal part of the internal carotid artery. There are special nerve end organs in the wall of this sinus which are sensitive to increases and decreases of the blood pressure. By a reflex arc, the sensory limb of which is through the glossopharyngeal nerve, stimuli are mediated to the medulla which result in increases or decreases of the heart beat, the pulse rate and the level of blood pressure.

*The Vagus Nerve.* The vagus nerve is a somatic and visceral sensory and motor nerve. Its sensory fibers arise from the ganglion cells in the nodosal and jugular ganglia. Most of these are visceral sensory fibers, but there are a few somatic sensory fibers which supply sensation to the posterior part of the external auditory meatus. The somatic motor fibers arise from the nucleus ambiguus and supply the muscles of the pharynx and larynx. Visceral efferent fibers arise from the dorsal nucleus of the vagus and they supply thoracic and abdominal organs, including the heart, the esophagus, the stomach, the small intestines and pancreas.

The vagus nerve leaves the cranial cavity through the jugular foramen in company with the 9th and 11th cranial nerves. As it leaves the jugular foramen, two gangliform enlargements, the jugular ganglion and the nodosal ganglion are noted. At the base of the skull it extends down in the carotid sheath, lying between the internal jugular vein and the internal carotid artery, to the upper border of the thyroid cartilage and between the common carotid and the internal jugular vein to the lower end of the neck In neck dissections, important branches of the vagus include the superior laryngeal, and the recurrent nerves. The superior laryngeal nerve is given off from the vagus in the region of the *middle of the nodosal ganglion. It extends down* behind the internal carotid artery and lateral to the pharynx Its two terminal branches, the external and the internal branches, supply the larynx The recurrent laryngeal nerve is given off differently on the two sides. On the right side it arises from the vagus in front of the subclavian artery and circles around the artery from in front backwards. It extends obliquely upward to the side of the trachea, behind the common carotid artery and in company with the inferior thyroid artery On the left side it is given off to the left of the arch of the aorta and winds around this vessel and extends up to the side of the trachea in company with the inferior thyroid artery and between the trachea and the esophagus. It supplies all of the muscles of the larynx with the exception of the cricothyroid which is supplied by the superior laryngeal nerve.

*The Internal Jugular Vein.* The most constant vein among those of the neck is the internal jugular. The internal jugular vein extends down from the jugular foramen at the base of the skull. As it courses vertically down the neck it is at first lateral to the internal carotid artery, then lateral to the common carotid artery. At the lower end of the neck, it joins with the subclavian vein to form the innominate vein. This is the case on both sides. Several large veins may empty into the internal jugular vein. Many of these have to be doubly ligated and cut during extensive dissection of the neck. These include the facial, the lingual, the superior and middle thyroid veins. The external jugular is in communication with the internal jugular but usually empties at the lower end of the neck into the subclavian vein. A good exposure of the internal carotid artery in the carotid sinus neighborhood necessitates doubly ligating and sectioning several veins that empty into the internal jugular.

In dissections of the neck, several important structures are watched for. Among the nerves the vagus, the hypoglossal, and the spinal accessory should be carefully guarded from possible injury. The transverse cervical and posterior auricular nerves which are seen on the posterior and lateral aspect of the middle third of the sternocleidomastoid may have to be sacrificed by section. The descending branch of the hypoglossal may be sectioned, if necessary. Among the veins, the superior thyroid, the common facial, the lingual, the middle thyroid, and the pharyngeal may have to be doubly ligated and cut. In dissections of the neck the use of an electrical stimulator is worthwhile in noting motor and sensory nerves, particularly if the operation is being done under general anesthesia.

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## *Anterior Fossa*

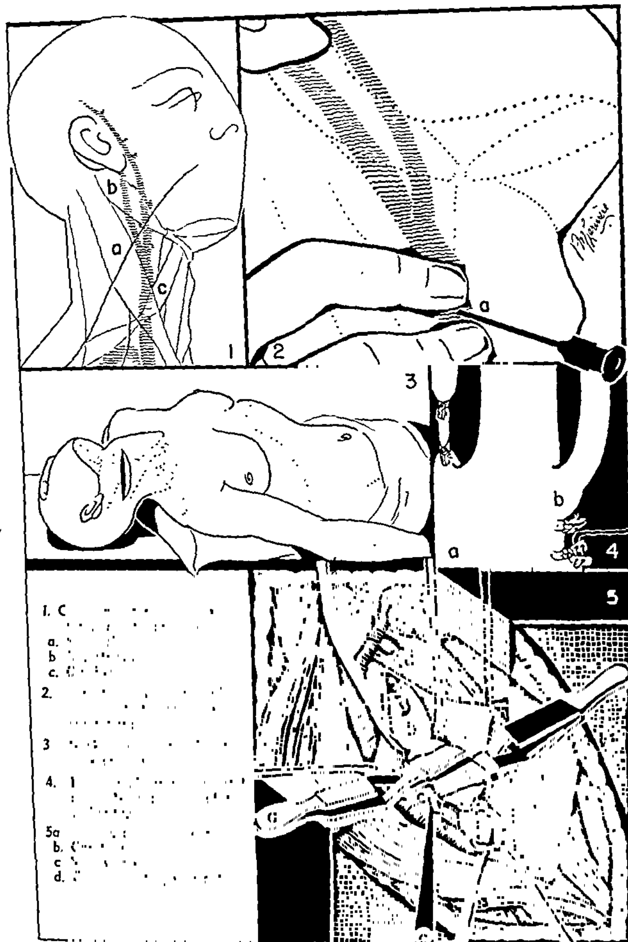
The anterior fossa is made up of the orbital plate of the frontal anteriorly and laterally, and the lesser wing of the sphenoid posteriorly, which also forms the posterior margin of the anterior fossa neighborhood. The lesser wing of the sphenoid extends medially to the anterior clinoid process of the sphenoid. Between the two orbital frontal plates and the roof of the nose is found the ethmoid bone which consists of a horizontal or cribriform plate forming a part of the base of the anterior fossa in the midline. The perpendicular plate constitutes a part of the nasal septum and the two lateral labyrinths which contain the ethmoid air cells. The cribriform plate is traversed by many foramina for the passage of the olfactory nerves on either side of the midline. In the middle of the horizontal plate anteriorly is a bony process, the so-called crista galli, which serves for the attachment of the anterior termination of the cerebral falx On either side of the midline, the horizontal plate is traversed by the anterior and posterior ethmoid foramina. The olfactory bulb is located in the grooved cribriform plate immediately next to the midline and lateral to the crista galli.

SURGICAL PROCEDURES

The position of the carotid complex in relation to the neck structures is shown in *1*, with *a* outlining the sternocleidomastoid, *b* the posterior belly of the digastric muscle, and *c* the omohyoid muscle. The carotid complex is easily palpable. The position of the carotid sinus and the level at which the common carotid branches into the external and internal carotid vessels may vary in different individuals, but if it is desired to inject the common carotid, the needle should be introduced below the level of the upper border of the thyroid cartilage. With the patient supine and the head extended and turned with the side to be injected uppermost, palpation of the carotid complex is more easily accomplished. Such a position also fixes the vessels so that the possibility of movement in the path of the needle tip is less likely. After locating the vessel and either keeping the index and long fingers over it as shown in *2*, or holding the vessel between the index finger and the thumb, or the index and the long fingers, in such a way that the vessel will not move laterally or anteriorly, one introduces an 18-gauge needle after anesthetizing a very small portion of the skin with ½ of 1 per cent procaine hydrochloride solution. In many instances, the needle can be introduced with ease. After insuring a good flow one may proceed with the injection of the dye, either 35 per cent diodrast® or thorotrast.® A stout rubber tubing of 1 mm. bore with an adapter on the one end is attached to the needle. On the other end of the tubing is a three-way stopcock which permits the introduction of the dye into the vessel in one position, turns off the flow in another position, and in a third position, permits the fluid to flow out through a third opening in the stopcock. A 10 cc. syringe is used to inject the dye as rapidly as it is possible and just as the injection is almost completed, a signal is given for x-ray exposure of the head, usually lasting one-fourth to one-sixth of a second. A second and third exposure for capillary and the venous phase may be made 1 second and 2 seconds after the completion of the injection. If, on the other hand, one uses the Fairchild, the Jarre or other serial cameras, consecutive exposures are made.

In some cases, there may be thrombosis of the internal carotid artery[191] and in order to visualize this condition by angiography, the common carotid should be injected quite low and an exposure of the neck, as well as the head, is made so that records are obtained of the dye in the vessel. Under these circumstances it is best to signal for exposure when the dye is halfway injected, so that some retrograde visualization of the common carotid is also obtained, giving a very convincing picture of the pathological condition

To do an open angiogram or for carotid ligation, the method shown in *3* and *4* may be used. In *3*, the position of the incision is given. This par-



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a
b
c
2
a
3
4
a
b
5
1. C
a.
b
c.
2.
3
4. 1
5a
b. C
c
d.

allels the creases of the neck, extending from a point lateral to the upper third of the sternocleidomastoid, encircling the neck downward and forward toward the middle of the thyroid cartilage. After the platysma and some external veins are incised and properly secured, the sternocleidomastoid muscle is exposed and its inner and anterior border is dissected and the muscle is retracted posteriorly. The pulsations of the carotid sheath may now be easily felt. The carotid sheath is now opened but as this is done, the descending limb of the ansa hypoglossi may be seen on the anterior medial aspect of the sheath. This should be left intact. The dissection is extended further and the internal jugular vein, the carotid complex and the vagus nerve are visualized. The internal and external carotid arteries can be easily dissected free. The internal jugular is lateral to the artery and also covers it anteriorly. Between the jugular and the carotid, the vagus nerve can be seen. *It is important, particularly if ligation of the vessel is contemplated, always to isolate and visualize the vagus.* In order to expose the external and internal carotid branches of the common carotid, it is necessary to doubly ligate several venous channels, particularly the facial and the external jugular. After this is done, exposure may be easily obtained all the way to the base of the skull. As this dissection is made, the 12th cranial nerve can be seen extending across the external carotid artery to the base of the tongue. The ansa hypoglossi is given off as the nerve crosses the external surface of the carotid and extends downward on the anteromedial surface of the carotid sheath.

The carotid artery may be ligated at the common carotid level, definitely below the carotid sinus area or at the internal carotid level about 1 inch above the bifurcation. In this way the possibility of injury or tear due to the presence of a plaque in the wall at the bifurcation is minimized As shown in *5*, after the carotid artery has been exposed, bulldog clamps are applied *and held in place for 30 minutes or longer, the procedure having been done* under local anesthesia. One can note whether or not there are any untoward symptoms from the obliteration of the artery If no untoward symptoms are noted a narrow umbilical tape is used to tie the common carotid in two places as shown in *4*. After using a square knot, a silk suture is used to hold together the ends of the umbilical tape as shown in *4* In this way the possibility of slipping of the knot is minimized.

In *5*, the bulldog clamps are shown on the common carotid artery at *a*; *b* is the carotid sinus with the external and internal carotid arteries shown a little above the bifurcation, *d* is the common facial and external jugular cut after ligation; *c* is the vagus nerve held up with a hook Immediately lateral to the carotid may be seen the internal jugular vein and external to it is the sternocleidomastoid muscle. Medial to the carotid complex is the omohyoid muscle.

When the open method of angiography is used, after the common, internal and external carotid arteries are exposed, an 18-gauge needle is inserted into the desired vessel As the injection proceeds, the vessel proxi-

mally should be obliterated so as to get a high concentration of the dye in the circulating blood. After completion of the procedure, when the needle is removed, there is much bleeding from the needle puncture point and this may be stopped by compression with gauze for two to four minutes. Usually, we compress this point while the x-rays are developed. By the time the x-rays are developed and brought in for inspection the bleeding has usually stopped. After thoroughly cleaning out the wound with saline solution the wound is closed in layers with interrupted silk sutures.

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### *Carotid Bifurcation, External and Internal Carotid Arteries*

The external and the internal carotid arteries are formed at the upper border of the thyroid cartilage. The external carotid is in a position anterior to the internal carotid artery. Again, in the lying-down position with the face turned away from the side of operation these relationships may be confusing. At the junction of the external and the internal carotid arteries is a bulbous enlargement covered with connective tissue containing many nerve fibers, constituting the carotid sinus. The carotid sinus region can be denervated by removing layer after layer of connective tissue containing these nerve fibers. In the older individual the artery may be torn, during such a dissection. The carotid sinus denervation is *done just as effectively by section of the 9th cranial nerve intracranially*, and this should be preferred to the removal of the connective tissue lining on the carotid sinus neighborhood.

The external carotid artery usually begins to give off branches at its junction with the internal carotid. These are the superior thyroid, the lingual, and the external maxillary branches. The occipital and the posterior auricular are given off in the same region. As the artery courses up the neck, it is crossed by the hypoglossal nerve and by the lingual, the common facial, and the superior thyroid veins. The digastric and the stylohyoid muscles also cross it laterally and anteriorly. Medially, the artery is on the hyoid bone and the wall of the pharynx. Posterior to the external carotid are the superior laryngeal nerve at its origin from the vagus and the internal carotid artery. Higher up, the internal and the external carotid arteries are separated from each other by the styloglossus and stylopharyngeus muscles, as well as the glossopharyngeal nerve. A little further up, the parotid gland covers the external carotid. It is deep to the facial nerve, and parotid tissue separates it from the facial nerve. The terminal branches are the superficial temporal and the internal maxillary. It also gives off the ascending pharyngeal artery.

## Cerebral Vascular Disease

Cerebral hemorrhage was early and clearly recognized, while embolism and thrombosis were not known until the early part of the nineteenth century. The concept that hemorrhage in the brain disturbs the normal flow of animal spirits into the organs of sense and motion resulting in hemiplegia and unconsciousness was a theory inherited from Galen in the second century. Wepfer, in 1658, gave an excellent description of cerebral hemorrhage in his book on apoplexia. He also described accurately the blood vessels at the base of the brain, two decades later called the circle of Willis.

Although aneurysm is mentioned in the works of Aetius in the sixth century, the term arteriovenous aneurysm was apparently coined by William Hunter in the eighteenth century. Aneurysms in the head and brain are mentioned only as possibilities prior to the nineteenth century. In the early part of the nineteenth century many descriptions, including careful neurologic data, of aneurysms of the base of the skull and brain exist. Coe and Swayne were the first to ligate the carotid artery in the neck for intracranial extradural aneurysm with success in 1855. Moniz[311], in 1927, described the technique of angiography. The importance of this procedure in the diagnosis and management of cerebrovascular disease cannot be overemphasized. A monograph by Dandy[112] in 1944 on intracranial aneurysms has founded a surgical concept of treatment. Anticoagulant therapy which has been successful in cardiovascular disease also is being used for patients who have cerebrovascular disease. Up to the present time, its value has been questionable. Cervical stellate block, discussed and suggested by Leriche in 1934, has been revived by Gilbert and DeTakats in 1948. In patients with thrombosis the use of stellate blocks has been encouraging.

The surgical treatment of massive intracranial hemorrhage has been considered mainly during the past fifty years. We feel that the following steps are important in management of patients with cerebrovascular disease.

1. An accurate history of the present illness and past events pertinent to the patient's condition.
2. Neurologic examination for the localization of the lesion, roentgen studies of the skull and an electroencephalogram.
3. A lumbar puncture with recording of the spinal fluid pressure, and examination of the fluid for blood content, cell count, total protein and serologic data.
4. If the disability remains constant for twenty-four hours on conservative therapy, and if the patient's condition permits, angiography by the percutaneous method is used to identify the type and site of the lesion.
5. If a diagnosis of cerebral thrombosis is certain, repeated stellate blocks may be used.
6. If a massive intracerebral hemorrhage is identified, evacuation by trephine may be first attempted. The local instillation of thorotrast[x] may outline the extent of the collection after aspiration
7. If signs of increasing intracranial pressure continue or if evacuation by

trephine is not adequate, removal of the lesion by appropriate exposure through craniotomy may be necessary.

8. The surgical removal of a lesion which may cause a repetition of the bleeding is worthwhile.
9. Rehabilitation should be begun as soon as possible in the hospital.

It is obvious that many patients with cerebrovascular disease need not undergo the management outlined above. A single short period of weakness or numbness in one half of the body or a short period of aphasia, followed by normal activity within a matter of hours is obviously not the type of symptom complex deserving this regime. If the patient has repetitions of focal symptoms and signs one may then advise special studies.

In the presence of signs of compression (headaches, increasing stupor, lowering pulse and respiratory rate, increasing blood pressure, shifted pineal shadow), exploration may be indicated. It may be safer to explore through a trephine opening, evacuate the collection and thus relieve the increasing intracranial pressure. Angiography may be done later to determine the origin of the bleeding.

The pathologic lesion in many of these patients with massive intracerebral hemorrhage is a semiliquid collection with necrotic brain tissue constituting the lining of the wall of the mass. This lining of softened necrotic brain tissue may become mixed with semiliquid collection. Visualization of the lesion is possible by injecting diodrast® or thorotrast® into the cavity of the collection following aspiration or removal of the contents. In some cases, there may be clotted material in the lining of the wall with liquid and semiliquid hemolyzed material toward the center of the cavity. The collection is usually located in the temporoparieto-occipital area and if the patient has a homonymous hemianopsia in addition to the hemiparesis or hemiplegia, such a location is most likely. A trephine placed 1 inch superior and ½ inch posterior to the ear will permit introduction of a blunt needle into the collection. If no collection is noted, or if the patient does not seem to improve on repeated aspiration of the hematoma, then an appropriate craniotomy to explore the area of the mass lesion is indicated. The clot is then removed through a transcortical incision or by uncapping. The collection which causes shifting of the ventricles or the vascular system would have to be rather large. In many instances, they have been over 30 cc. in size.

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### *Vertebral Angiography*

Vertebral angiography may also be of diagnostic importance. This visualizes the posterior portions of the vascular tree including the basilar artery, the posterior cerebrals, posterior communicating and superior, middle and inferior cerebellar branches. A lateral and occipital view is made following a 10 cc. injection of either diodrast® or thorotrast® by either an open or closed technique.

The preferable closed method is similar to that used for carotid in-

(*Continued on page 120.*)

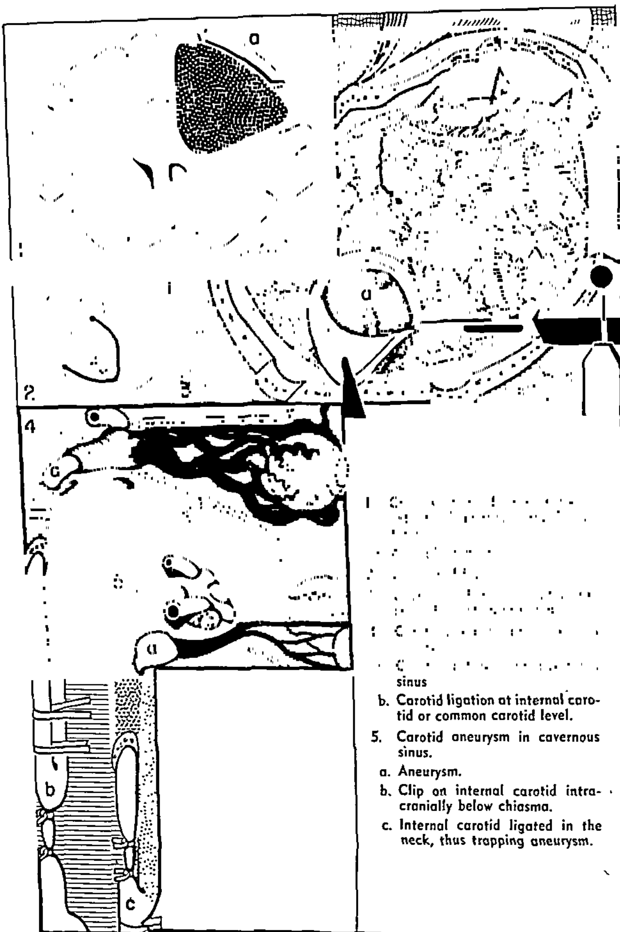
In *1a*, cross section of the brain containing an intracerebral hematoma in the frontoparietal region is shown. The area of uncapping of the brain to reach the clot cavity is represented by *a*. In *2* is shown the scalp incision and the bone flap to reach the clot. In *3* the brain has been exposed and the uncapping is being carried out. The surface of the brain immediately over a presenting clot is discolored, thin and has a cystic quality upon palpation. In some instances, there may be rupture with subdural hemorrhage. A portion of this thinned out, discolored brain may be excised with the electrocautery after insuring hemostasis. The cavity of the clot now is entered and by suction the fluid portion, as well as the more solid portion in the wall of the cavity, is removed. Bleeding points are secured. The cavity is washed out with saline. Further bleeding may be controlled by coagulation. Lighted retractors are a valuable aid for inspecting the cavity.

In the diagnosis of such lesions, the use of air studies and angiography, or both, may be helpful. The importance of angiography cannot be overemphasized since it will also show the presence of abnormal vasculature which may require removal if a cure is to be obtained.

In *4* is an example of a carotid cavernous arteriovenous aneurysm. At *b* the common, the internal and external carotid arteries are seen. The common carotid in this instance is shown ligated with umbilical tape. At *a* the carotid extends through the foramen lacerum into the cavernous sinus region. Anteriorly the eye with enlarged veins extending toward the cavernous sinus, is diagramed. A ligation of the common carotid artery may be sufficient to improve this condition. If improvement is not obtained the internal carotid should be ligated. In other instances, it may be necessary to ligate the internal carotid intracranially, decompress the orbit and ligate the enlarged veins. In most cases, ligation of the internal carotid artery is sufficient. The use of long strips of muscle obtained from the sternocleidomastoid to pack the internal carotid to the base of the skull may be helpful.

In *5* is shown an aneurysm of the internal carotid artery in the cavernous sinus in an extradural position Such an aneurysm, as shown at *a*, may be trapped between ligation shown at *c*, and a clip on the intracranial portion of the internal carotid artery shown at *b*. In most instances the ligation of the common carotid or the internal carotid at *c* is sufficient. An extradural aneurysm of the carotid in the cavernous sinus results in the involvement of the trigeminal complex with sensory changes in the ophthalmic and maxillary divisions There may be a third and a sixth cranial nerve paralysis, as well.

Cerebrovascular accidents include cerebral hemorrhage, thrombosis and embolism The problem of hemorrhage involves the rupture of the usual stroke vessels, of intracranial aneurysms; of vessels in pathological tissue




sinus

b. Carotid ligation at internal carotid or common carotid level.

5. Carotid aneurysm in cavernous sinus.

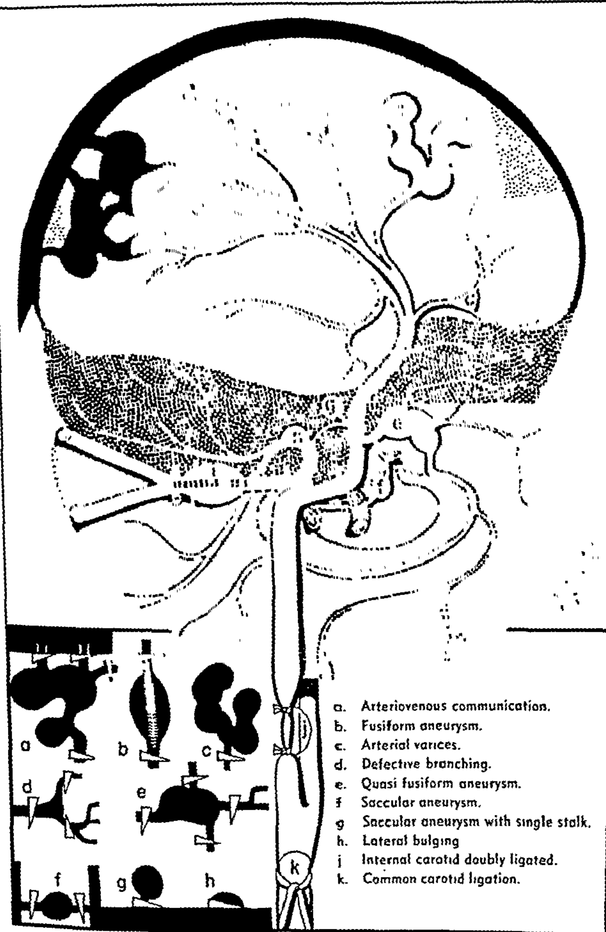
a. Aneurysm.

b. Clip on internal carotid intracranially below chiasma.

c. Internal carotid ligated in the neck, thus trapping aneurysm.

Intracranial aneurysms may be intradural or extradural. Two examples of the extradural type, namely, aneurysm in the cavernous sinus and an arteriovenous communication in the cavernous sinus are shown in the preceding figures. Management of an extradural aneurysm in the cranial cavity is fairly well standardized and consists of ligation of the common or internal carotid artery in the neck, and possibly also, ligation of the internal carotid artery as it enters the cranial cavity at the base of the brain. The intradural aneurysms are a serious problem. Management of such aneurysms by conservative or operative treatment is still a matter of debate. Operative treatment includes the indirect method of managing these lesions; namely, by tying the common or internal carotid on the same side as the aneurysm and the direct attack upon the aneurysm by exposure. Direct attack may consist of placing a clip on the neck of a saccular aneurysm, or the aneurysm may be trapped by applying clips to the feeder vessels. The entire mass may be excised in some cases. The aneurysm may rupture during the manipulation, and its cavity may be packed with muscle. Simultaneous carotid ligation almost always is necessary in such a case. Fusiform aneurysms on the larger vessels of the brain are usually inoperable. Particularly is this true if the aneurysm involves the middle cerebral near the circle of Willis. Excision of such a mass invariably results in hemiplegia of the opposite half of the body. Fusiform aneurysms in the more distal portions of the main arteries of the brain may be excised with less disability. Arterial varicosities may be excised if they are in the more distal portions of the principal arteries of the brain Many arteriovenous communications can be treated surgically. Such malformations, when they occur on the right side, and if they are in the more silent portions of the brain, are lesions for surgical intervention. Very large arteriovenous malformations involving the motor centers, particularly those on the left side are best treated conservatively except when the patient already has serious disability such as a contralateral paralysis

In the accompanying figure, the vasculature of the brain has been diagrammatically represented to show various types of vascular abnormalities. The lateral aspect of the brain is shown above with the distribution of the middle cerebral artery The base is represented by the darkly shaded area in the middle The circle of Willis and the distribution of the posterior cerebral are shown Below is the medial aspect of the hemisphere with the distribution of the anterior cerebral and a portion of the posterior cerebral arteries. An arteriovenous malformation is shown at *a* A fusiform aneurysm on one of the branches of the middle cerebral artery is shown at *b* A varicosity of one of the branches of the middle cerebral is diagramed at *c*. An aneurysmal dilatation from the defective branching is seen at *d* A quasifusiform aneurysm of the anterior cerebral, vestigial in origin, is shown at *e* The usual saccular aneurysm, with a small neck at the carotid siphon is seen at *g* A sac-


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c
d
e
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g
h
j
k
a. Arteriovenous communication.
b. Fusiform aneurysm.
c. Arterial varices.
d. Defective branching.
e. Quasi fusiform aneurysm.
f Saccular aneurysm.
g Saccular aneurysm with single stalk.
h. Lateral bulging
j Internal carotid doubly ligated.
k. Common carotid ligation.

cular aneurysm in the course of the anterior cerebral communicating artery is shown at *f*. A lateral bulge in the posterior cerebral artery is represented by *h*. Below are figures demonstrating ligation of lesions by means of silver clips.

## Intracranial Suppuration

### Historical

It is of historical interest that Lebert, in 1856, wrote the first systematic account of brain abscess, which was based upon 80 records, of which 15 were from the 18th century; 5 were personal cases. He wrote, "We must speak more decisively against any attempt at operation, for opening a brain abscess is even from the theoretical point of view not rational". He believed it a "foolhardy" procedure. By 1881, however, opinion held that drainage should be accomplished and it was stated "the sole resource of the surgeon in managing collections of matter in the brain or its meninges is to let it out. The operation should not be unnecessarily delayed; the vent to the matter should be sufficiently free, and should be kept so until the cure is complete". In 1886, 1887, and 1888 otitic abscesses were drained and cured by Gowers and Barker, Greenfield, and Ferrier, respectively. In 1887 Schwartze performed the first recorded successful operation for a cerebellar abscess which was drained through the mastoid antrum. Another landmark in the treatment of brain abscess was the monograph published in 1893 by William Macewen entitled, *Pyogenic Infective Diseases of the Brain and Spinal Cord*. His results by a simple but effective surgical management still remain unexcelled It is of note that Macewen did not credit "drainage tubes for the success of his treatment". He stated, "after evacuation of an acute abscess, drainage tubes are of little value, provided the whole of the infected matter has been removed. If doubt exists on this point, a drainage tube is introduced. There can be no doubt that the pulsations of the brain caused by striking against the tube, produce an irritation which is increased if the tube be rigid In chronic abscess, the drainage tube may be required".

At the beginning of the 20th century the otologist's role in the surgical treatment of the nontraumatic types of suppuration became dominant. The results of treatment, however, were discouraging due to a lack of uniformity of concepts of surgical management and delay in treatment Ballance pointed out in 1907 "the intra-meatal-aural specialist of the past generation was content to flit helplessly about his chosen canal in the manifest presence of lethal complications Is it or is it not true that the intranasal specialist of the present day, with some brilliant exceptions, may at times be unduly influenced by the tradition of his otological kinsman"

The rapid advances of neurological surgery in the first decades of the 20th century resulted in placing the treatment of these lesions into the hands of the growing specialty of neurological surgery. As the neurological surgeons dealt with this difficult problem, various individual methods of treatment were designed and proposed by *Dandy*[101], *King*[259], *Coleman*[85, 86], *Horrax*[221],

Kahn[247, 248], Vincent, and others. Out of these suggestions and now with the aid of antibiotics, there has developed a more standardized set of procedures which have proved effective in treating this lesion.

Percival Pott[358] in the 19th century had important success in treating epidural abscesses and thus deserves a recognition similar to that of Macewen for such early success. Subdural abscess, a more common lesion, was early recognized as usually fatal. Recovery, however, was reported in a patient operated upon in 1699 by De LaPeyronie who was stated to have performed the first successful operation for a subdural abscess. Other successes occurred, notably those of Macewen, who reported three cases surviving after surgical drainage, all in conjunction with a mastoidectomy. It is of interest that no record of successful operative management of the fulminating acute subdural abscess, resulting from paranasal sinus disease was found in the consulted literature of the 18th and 19th century, although this complication was recognized in autopsy material.

Since the use of antibiotics, along with early recognition of the disease, a successful outcome has now become the rule, instead of a rarity.

## Surgical Procedure

A subdural abscess usually is a complication of paranasal sinus or mastoid disease. The onset is fulminating and usually the signs and symptoms include headache, dizziness, beginning stupor, convulsive manifestations and other focal involvement, such as aphasia, weakness or paralysis of one half of the body. There may be an accompanying osteomyelitis of the skull. It is most important to reach an early diagnosis in such a case, since surgical drainage in conjunction with antibiotic therapy is quite successful.

In the surgical management of an acute subdural abscess, several openings are made in the skull overlying the collection. Three or four such openings may be necessary At times, the lesion is bilateral, requiring bilateral openings. Upon incising the dura, there is usually drainage of pus in large quantities The area of the collection is then washed out with penicillin solution in saline. A tube may be inserted into the subdural space and 25,000 units of penicillin instilled daily for 3 or 4 days. The presence of concealed loculations of pus, as between the hemispheres, on the falx or over the tentorium, may require further attention. In failing to obtain a good response following drainage, further diagnostic procedures are indicated to locate residual or additional loculations. Before the use of antibiotics, these cases were uniformly fatal; since, a fatality is uncommon.

The intracerebral or intracerebellar abscess may often be treated by simple tapping, aspiration and the instillation of penicillin. If a cannula is inserted into an abscess cavity pus may be evacuated and 50,000 units of penicillin then injected into the cavity before the withdrawal of the needle. Injection of 5 cc. of thorotrast® in addition will delineate the cavity in subsequent roentgen studies The progress of the lesion can be thus observed

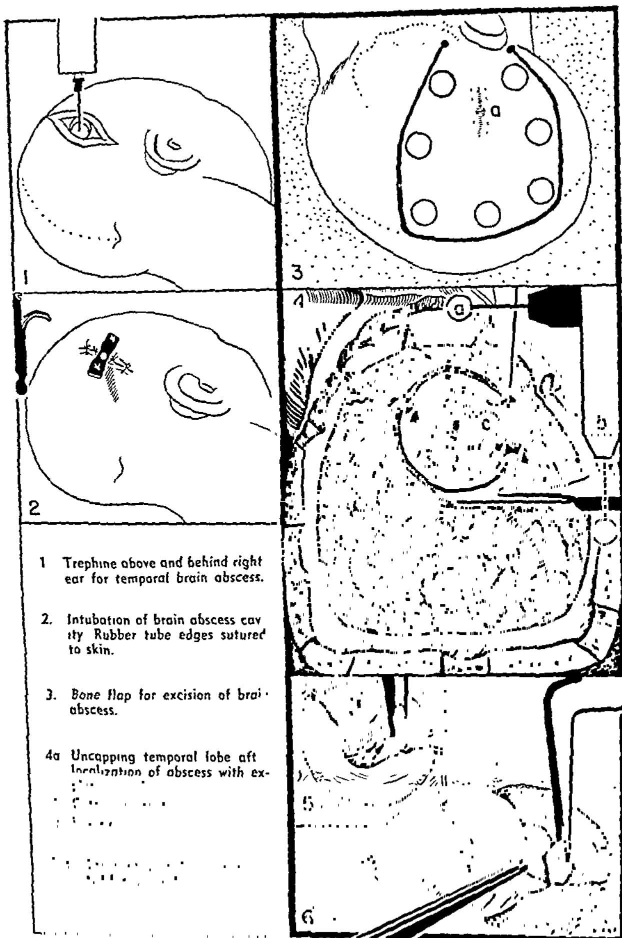
A second method of management employs intubation of the abscess cavity as shown in *2*. A rubber tube may be inserted into the cavity with several openings at the end of the rubber tube. The tube is then bisected as shown in *2*, and sutured to the scalp. Daily penicillin injections may be administered through this intubated mechanism. Although a time-honored and effective method, the value of the drainage tube is open to question.

In *3*, *4*, *5* and *6* is shown an abscess treated by excision, a step which may ultimately follow simple tapping. This is a temporal lobe abscess following middle ear and mastoid infection. A bone flap is turned down with a previous opening into the abscess cavity as shown at *3a*, in the center of the bone flap *3*. The wall boundaries of the abscess may be easily located by cannula exploration. When the position of the abscess has been demarcated the cortex immediately overlying this area is uncapped as shown in *4*. At *a* and *b*, the surface vessels are being cauterized and the cortex incised with a cutting current applied to a scalpel. The abscess wall is then visualized by blunt dissection with cottonoid at the end of a bayonet forceps, as shown in *5* and *6*. The abscess may be multiloculated; or multiple abscesses may be contiguous. After removal of the abscess with its wall intact, if possible, the bordering area is carefully debrided and penicillin solution instilled in the area. The dura is closed tightly. The bone is replaced and held in place with wire sutures and the skin is closed in layers of interrupted silk sutures. The position of the abscess may be marked on the scalp and postoperatively for two or three days, 25,000 units of penicillin injected through an appropriate burr opening of the bone flap with a spinal needle.

Abscesses secondary to compound fractures, and particularly those of the penetrating type of war wounds, differ from the civilian type of abscess. Usually these are not encapsulated but are purulent areas involving the missile track. Wound infection and the presence of fragments in the tract of the penetrating wound help diagnose a complicating abscess Air study may show the presence of a ventricular distortion.

The management of this type of abscess is by complete excision or debridement of all foreign bodies, the necrotic brain and the surrounding fibroglial tissue by suction. After complete excision this area may be irrigated locally with penicillin solution. The dura cannot usually be closed. A dural graft is avoided. Thus, the scalp is closed over the brain and the cavity produced by the debridement. On subsequent days, injection of 25,000 units of penicillin into the area of the cavity may be done. Where there is loss of scalp or in the frontal area where cerebrospinal rhinorrhea requires dural closure, a temporary dural graft may be necessary. This may be removed in 10 days and the area grafted with a split thickness skin graft.

The diagnosis of abscess and its position in the cranial cavity may depend upon signs and symptoms. The use of pneumoencephalography, angiography and electroencephalography may be necessary for accurate localiza-




1 Trephine above and behind right ear for temporal brain abscess.

2. Intubation of brain abscess cav ity Rubber tube edges sutured to skin.

3. *Bone flap* for excision of brai· abscess.

4a Uncapping temporal lobe aft localization of abscess with ex-

tion. A history of previous infection; co-existent infection of the paranasal sinuses, the middle ear, the presence of an intrathoracic infection, an area of osteomyelitis of the skull, are valuable data in the evaluation of the type of pus collection. If the patient, treated by initial tap or tap with drainage, is not showing improvement day by day, then the necessity for further steps in treatment is indicated, preceded by diagnostic procedures. The possibility of a subdural and intracerebral abscess in the same patient should be kept in mind. Two out of five patients in one group of successfully treated subdural empyema, also had intracerebral abscesses, necessitating evacuation 4 to 6 weeks later. It is quite likely that contamination occurred in both locations simultaneously. The life history of a subdural collection is one week to ten days, whereas an intracerebral abscess may become encapsulated and cause signs of compression four to six weeks after the onset of the infection.

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*Vertebral Angiography (Concluded)*

jection. The #18 gauge needle is directed dorsally, but more medially and slightly upward to strike the vertebral artery between the transverse processes of the 4th and 5th or 5th and 6th vertebrae.[419] Other methods, including an open technique, described by Moniz,[311a] and Ecker[130a] may be of service.

*Intracranial Suppuration*

In many patients with brain abscess there may be a ventriculitis or meningitis. The presence of such complications should be ascertained by ventricular tap and lumbar puncture. Antibiotics should be administered into the spinal subarachnoid space and into the ventricles if indicated. Several patients in our series of cases with brain abscess had associated ventriculitis and meningitis, and recovered with appropriate management of these various complicating phases of the infection.[190, 191]

# Posterior Fossa and Cranial Nerves

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## Suboccipital craniectomies—historical

ATTEMPTS at removal of tumors in the posterior fossa failed so frequently that surgeons became reluctant to undertake this operation in the early period of modern surgery. At the close of 1893, Starr[412] reported that fifteen cases were known to have been operated upon with only one successful removal of the tumor and recovery of the patient. Starr stated "discouraged by this record for a number of years I refused to recommend operation in cases of cerebellar tumor". Oppenheim classified tumors of the cerebellum as inoperable. In 1902 Oppenheim's table reported a 71 per cent mortality; in 1903, Duret[128] reported a 50 per cent mortality, while Frazier's[149] collection of cases in 1904 showed a 42 per cent mortality.

With more attempts being made at approaching the cerebellum and other structures in the posterior fossa, greater experience resulted in perfecting surgical technique. Important observations were made by Horsley[231], Ballance[16], Borchardt[27, 28], Krause[239], Kocher[263], Frazier[149, 150] and Cushing[76] during this important developmental period from 1900 to 1910. Up to 1910 case records of cerebellar tumors collected by Frazier and Starr numbered two hundred and ninety-four. In this group one hundred and sixty-two tumors were found and removed. There was recovery from the operation with cure of the symptoms in fifty-nine patients.

The position of the patient was considered to be important, and both Cushing and Frazier found it advisable to put the patient in a prone position with the head on a specially devised headrest, which projected over the end of the operating table, permitting freedom of thoracic movements. Schede placed his patients well forward in a sitting position with the head flexed. Horsley and Krause employed a lateral position. DeMartel, in 1913, insisted that the upright chair position with the head flexed was the most satisfactory.

An osteoplastic flap, either unilateral or bilateral, with the base downward, was recommended by Krause. It was advocated in this operation that the occipital arteries be ligated before the formation of the flap. Krause also used a vertical median incision to expose the fourth ventricle and the vermis. A transverse incision was made perpendicularly at the upper end of the vertical incision, thus producing two triangular flaps. A midline incision was suggested by Frazier[155] in 1926 and was described as a "midline

bloodless approach." The operative wound used by Naffziger[121] was vertical without the upper transverse extension and this has won popularity. Straight or hockey stick, median or paramedian incisions also became popular during the first half of the twentieth century. Cushing[75] advised the crossbow incision which combined the commonly used mastoid-to-mastoid curved incision with a vertical or median cut which divided the soft parts to expose the spinous processes of the upper cervical vertebrae.

There was early agreement that a suboccipital craniectomy was more suitable than an osteoplastic flap for exposure of the posterior fossa structures, particularly since it was noted that the occipital muscles offered adequate protection to the underlying structures. More complicated exposures were used combining a small occipital bone flap with a suboccipital craniectomy and ligation of the lateral sinus. Frazier[119], Naffziger[121] and Sachs[181] suggested these procedures.

A successful exposure of the contents of the posterior fossa, regardless of the position of the patient and the type of incision used, at first, was a trying problem. Frazier pointed out that the designer of the human body did not intend this area to be exposed. Starr in 1910 observed that "the dura bulged strongly through the bony opening, indicating greatly increased intracranial pressure. When the dura was divided the cerebellar tissue protruded and it was necessary, in order to go on with the operation, to cut off quite an amount of cerebellar substance in order to palpate the parts below. The finger was introduced along the surfaces of the cerebellum but nowhere was it possible to reach the tumor". Starr felt that a bilateral approach was more suitable than the unilateral one since it allowed a greater amount of room for tumor removal. Starr also was impressed by the appearance of the cerebellum being herniated into the spinal canal and recorded "the existence of a marked ridge upon the cerebellar tissue showing the pressure that had been exerted along the edge of the foramen magnum and the cerebellar tissue had evidently been forced downward into the foramen at least three-quarters of an inch below its upper level". The relation of sudden death to medullary compression was also noted.

There was at first disagreement on the value of a ventricular puncture in the course of the surgical management of cerebellar tumors Frazier[119] stated in 1905, "Puncture of the ventricles is unfortunately an operation of unusual gravity and the danger attending it is so great in comparison with the possible benefit as to make it a procedure of questionable propriety". Greater experience however revealed the value of decreasing the intracranial pressure as well as the hemorrhage by evacuating the ventricular fluid The now common practice of ventricular tap and the insertion of a brain cannula in the ventricle during operation was recommended by Cushing.[76] Further surgical experience showed that it was possible to resect large portions of the cerebellum and the term "uncapping" was used to describe the removal of the lateral portion of a hemisphere, particularly for exposure of a cerebellopontine angle tumor. Dandy[116] reported on the value of vertical section through the vermis for deep tumor exposures In

1923 Dandy[39] also suggested a test for patency of the aqueduct and the fourth ventricle, by the use of a dye which could be observed at the site of the exposure. The importance, of course, of ventriculography in the successful management of these posterior fossa lesions only needs mention at this point.

## The Cerebellum

The cerebellum which lies in the posterior fossa presents two hemispheres separated by a median structure which is termed the vermis. Connections with the brain stem are by three sets of peduncles described by their location as the inferior, middle and superior, and termed, corpus restiformi (inferior), brachium pontis (middle), and brachium conjunctivum (superior). Functionally the cerebellum may be divided into the flocculonodular lobe which consists of the nodulus of the vermis and the flocculi, the latter being attached to the nodulus of the vermis through peduncles containing myelinated fibers. Involvement of the flocculonodular lobe results in trunk ataxia and it is the area usually involved by the medulloblastoma. The body of the cerebellum is separated from the flocculonodular lobe by the posterolateral fissure. The body is further subdivided into an anterior lobe and a posterior lobe by the primary fissure. The anterior lobe consists of the lingula, the anterior medullary velum, the central lobule and the culmen monticuli with their lateral extensions. The posterior lobe makes up the greater part of the cerebellum and it consists of the lobulus simplex, the medial lobule, the ansiform lobule, the posterior median lobule. The ansiform lobules are paired structures.

The cerebellum presents a cortical surface of the folia, characterized by uniformity of cyto-architecture, with a central white substance in which are located masses of gray matter on either side: the roof nuclei of the cerebellum. These include the nucleus dentatus, the nucleus emboliformis, the nucleus globosus, and the nucleus fastigii, beginning medially and extending to the lateral border.

Although all types of tumors may occur in the posterior fossa, the astrocytoma, the medulloblastoma and acoustic tumors are the most important. Studies by Cushing[33, 85, 87], Bailey[12, 14a] and Hortega made it possible to understand these tumors and their life history. The medulloblastoma was early recognized to be a dangerous tumor and attempts at extirpation involved a high mortality with no prospect of cure. A short period of improvement by irradiation of the medulloblastoma was reported by Cushing[91], Olivecrona and Lysholm, Wanke and others.

In 1931 Cushing[87] reported his experiences with the cerebellar astrocytomas Recognition was made and later confirmed that a radical procedure in a complete removal of this cystic type of tumor involved removal of what was termed the "mural nodule" often grossly identifiable within the cyst wall. The value of frozen sections made at the time of surgical treatment was also recognized.



Certain incisions are shown in the accompanying illustrations. In *1* is the *incision from mastoid to mastoid* just above the superior nuchal line. Laterally, in the mastoid region, the incision extends down toward the neck for 2 to 3 cm. This gives excellent exposure of the occipital squama, after the muscular tendinous tissue is incised just below the superior nuchal line and reflected downward. With separation of the midline structures and retraction there is also good exposure of the posterior arch of the atlas.

In *2* paramedian and median incisions to expose the squamous portion of the occipital bone on one or both sides are shown. The median exposure early was recognized as a bloodless route since only very few blood vessels were encountered as the dissection proceeded all the way down to the squamous portion of the occipital bone and the posterior arch of the atlas. The paramedian exposure, used in some cases for excision of acoustic neurinoma,[40, 225] is more bloody and there may be section of the occipital and the posterior auricular arteries which should be secured, and coagulated or ligated.

In *3* a reversed hockey stick incision is shown for exposing the cerebellopontine angle. Excellent unilateral visualization of the posterior fossa can be obtained through this incision. The shorter limb of the reversed L is 3 to 4 cm. above the superior nuchal line The skin is reflected laterally. The squamous portion of the occipital may be exposed either after complete reflection of the musculoperiosteal lining laterally, or after incision of musculoperiosteal attachment just below the nuchal line. Incision of the muscles at this point involves the trapezius, the semispinalis capitis, the obliquus superior and sternocleidomastoid muscles.

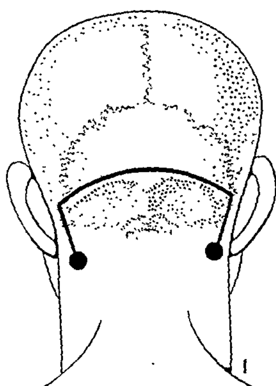
In *4* is shown the classical crossbow incision of Cushing, one line of the T extending from mastoid to mastoid above the superior nuchal line and the other line through the midline of the neck.

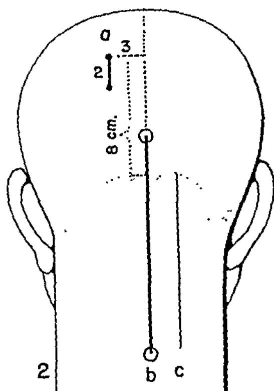
The midline incision is adequate to expose the vermis and both cerebellar lobes, as well as the region of the fourth ventricle. A unilateral exposure for an angle tumor can be accomplished either by a reversed hockey stick incision or a paramedian incision. If access to the superior surface of the cerebellum is sought, extensive craniectomy may be desirable, making it possible to bisect the lateral sinus as is described in the next few pages. In our clinic almost all posterior fossa operations are done in the sitting up position.

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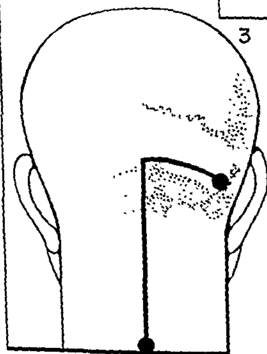
*Posterior Inferior Cerebellar Artery*

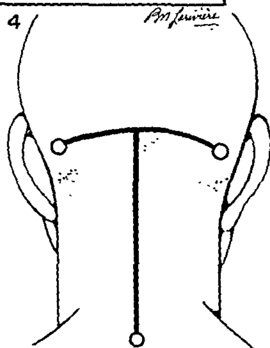
This artery arises from the vertebral and it extends posteriorly toward the inferior surface of the cerebellum. It divides into a medial and lateral branch In explorations of the cisterna magna and the fourth ventricle the medial branch of the posterior inferior cerebellar artery is brought into view




1. *Horseshoe incision*
2a *Incision for ventricular tap.*
b. *Median incision.*
c. *Paramedian incision.*
3. *Reversed hockey stick incision.*
4. *Cross bow incision.*





In *1* the posterior craniovertebral junction is illustrated. The superior and inferior nuchal lines are shown. At *a* and *b* large emissary veins usually are encountered above the foramen magnum in the midline, and lateral to the foramen magnum, at the hypoglossal foramen. At *c*, between the posterior arch of the atlas and the occipital bone, the vertebral artery may be encountered. At *d* the occipital emissary vein is noted. Both the occipital artery and the posterior auricular arteries may be sectioned when incising the musculoperiosteal junction at the lower border of the superior nuchal line. The greater occipital nerve is also cut.

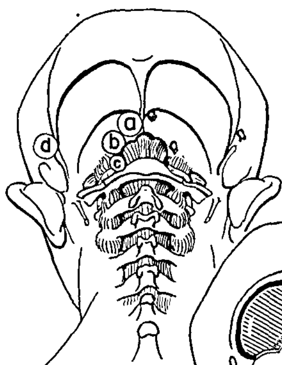
In *2*, with the intubated patient in the sitting position, the depth of the suboccipital and cervical exposure is indicated.

In *3*, *4* and *5* various sizes and types of openings in the squamous portion of the occipital bone and the first cervical vertebra are shown. In *3* a unilateral opening in the squamous portion of the occipital bone, not extending into the foramen magnum, is shown. This can be used for section of the 5th, 8th and 9th cranial nerves. In *4* a somewhat larger opening in the squamous portion of the occipital, also involving the foramen magnum, may be used for exposure of the 5th, 8th and 9th cranial nerves. With removal of a portion of the posterior arch of the atlas this exposure also may be used for section of the descending root of the trigeminal nerve. In *5* a bilateral suboccipital craniectomy is shown with removal of the squamous portion of the occipital bone from mastoid-to-mastoid, from superior nuchal line to the foramen magnum. The posterior arch of the atlas is also removed. All these exposures are possible through a median incision.

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### *Vertebral Artery*

The vertebral artery arises from the first part of the subclavian artery and extends to the foramen transversarium of the sixth cervical vertebra between the anterior scalene and the longus colli muscles. On the left side the vertebral artery is traversed anteriorly by the thoracic duct as well as by the vertebral veins, internal jugular vein and the inferior thyroid artery It extends up through the transverse foramina and after passing through the foramen transversarium of the atlas it turns backward and posterior to the superior articulating surface of the atlas. It enters the dural sac between the occipital bone and the posterior arch of the atlas. It then gains access to the lateral and anterior aspect of the medulla and unites with its fellow on the opposite side to form the basilar artery. In its course through the spine, it supplies spinal branches which enter the spinal canal through the intervertebral foramina and muscular branches In its course through the cranial cavity it supplies meningeal branches, the anterior spinal and the posterior spinal arteries The posterior inferior cerebellar artery and medullary and bulbar twigs are also branches.







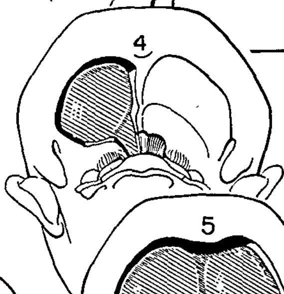
Head acutely flexed.

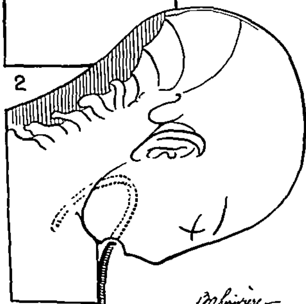
3. Unilateral suboccipital craniectomy.
4. Unilateral suboccipital craniectomy to the foramen magnum, atlas intact.
5. Bilateral suboccipital craniectomy and excision of *posterior arch* of the atlas.

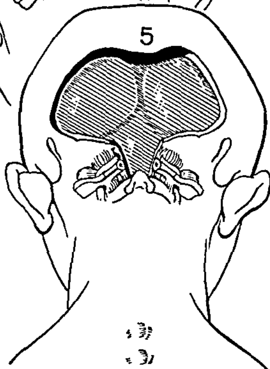
Head acutely flexed.

1a, b. Emissary veins.
c. Vertebral artery.
d. Occipital emissary vein.

2. Depth of incision and position of *endotracheal tube.*



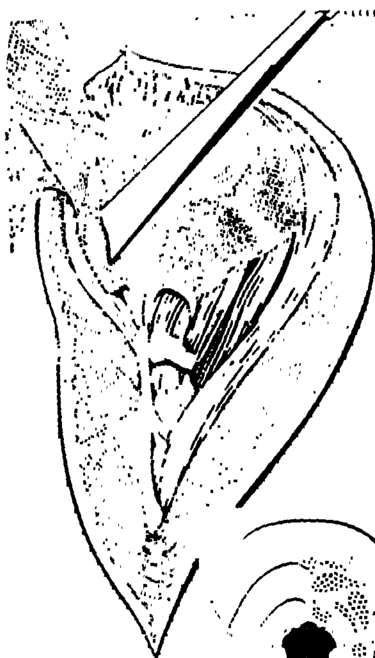



Through a median incision extending from a point 5 cm. above the superior nuchal line down to the 4th or 5th *cervical spinous process*, the squamous portion of the occipital bone and the posterior arch of the atlas are exposed. With the patient in the sitting position and the head flexed forward this can be done with greater ease. After incision of the skin and ligamentum nuchae the trapezius and semispinalis capitis muscles are separated. The median raphe is sought, since incision at this point results in minimal bleeding. Deeper, the splenius cervicis and the multifidus muscles are encountered on the *laminae* of the *cervical* vertebrae. The exposure of the squamous portion of the occipital is made possible after reflection of the trapezius (*1*), the semispinalis capitis (*2*), the obliquus capitis superior (*3*), *the rectus capitis lateralis* (*4*), *the rectus capitis posterior major* (*5*) and the rectus capitis posterior minor (*6*) muscles The positions of these muscles are diagrammatically shown in *2*.

In *3*, with the patient in the sitting position, the length and depth of this incision may be seen in a lateral view. The spinous process of the 2nd vertebra usually is exposed and if it is desirable it may be partially removed for better visualization of the posterior arch of the atlas. Usually the removal only of the spinous process is sufficient. In exposing the spinous process of the 2nd cervical vertebra or the axis, one has to section the attachment of the rectus capitis posterior major and that of the obliquus *capitis inferior. In exposing the atlas one has to section and reflect the* rectus capitis posterior minor which arises from the posteromedian tubercle of this bone.

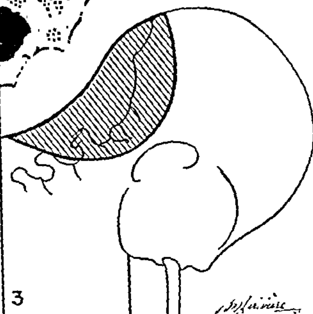
As the muscles are reflected and the squamous portion of the occipital bone is exposed, diploic bleeding from emissary veins may be stopped by the use of bone wax It is important to expose laterally to the mastoid emissary vein which may be prevented from bleeding with the use of bone wax. The posterior aspect of the foramen *magnum should be completely* exposed in its lateral portions and the same is true of the posterior arch of the atlas However, it is important to be careful since the vertebral artery may be injured, or large venous channels may be entered which empty into the vertebral plexus. Other small bleeding points may be controlled with electrocautery or the use of silver clips The use of scissors, a knife and a periosteal elevator is freely indicated in this exposure and the separation of muscles from their attachments to the squamous portion of the occipital and the first cervical vertebra



1. Subperiosteal exposure of occipital squama and arch of atlas with elevator and gauze. Median skin incision used.



2. Muscles of the occipital squama.
   1. Trapezius.
   2. Semispinalis capitis.
   3. Obliquus capitis superior.
   4. Rectus capitis lateralis.
   5. Rectus capitis posterior major.
   6. Rectus capitis posterior minor.



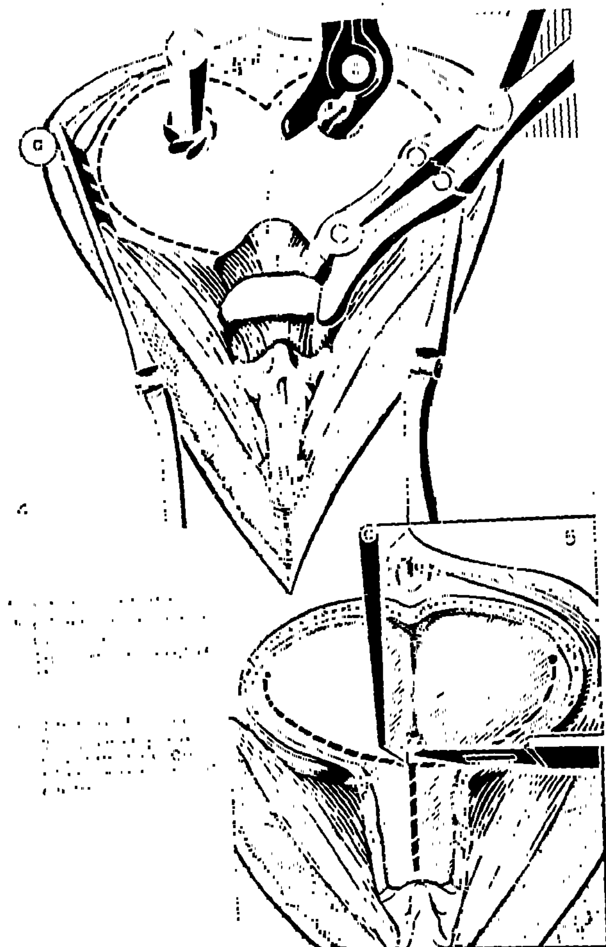
3. The depth of the wound for suboccipital craniectomy through a median incision.

## Removal of the posterior arch of the atlas

▶

Through a median incision the squamous portion of the occipital, the foramen magnum, and the posterior arch of the atlas have been exposed as shown in *4*. The dotted line indicates the area of bone for removal. This suboccipital bone is well visualized by adequate retraction of muscles as shown at *a*. At *b* the bone opening is begun with a Hudson drill, following the use of a perforator, and at *c* the use of a goose-neck rongeur for the beginning of the craniectomy is shown. In some cases the occipital squama, particularly at the midline, may be very thick. A Gigli saw may be used to advantage. The lateral portions of the squamous bone are rongeured away up to the lateral sinus impression. The Gigli saw is then passed from one side to the other under the heavy midline bone. If the lateral portions of the occipital squama are also thick and a goose-neck rongeur cannot be used to advantage, then a Kerrison rongeur is an aid in extending the craniectomy to the lateral sinus impression In the inferior and the lateral portions of the opening, the double acting straight rongeur or a rongeur with a curve at right angles to the long axis of the plane of the instrument may be used to advantage. At *d* the removal of the posterior arch of the atlas is shown, employing a goose neck rongeur. At times it is advantageous to have the spinous process of the axis partially or completely removed. With the patient's head flexed anteriorly the atlantooccipital and the atlantoaxial ligaments may be seen somewhat stretched. Around the foramen magnum it is important to extend the opening laterally so that the cerebellopontine angle may be exposed with the greatest of ease. The same is true with the posterior arch of the atlas, but on exposing this area as far laterally as possible, one may injure large arterial channels, particularly the vertebral and several large venous channels which empty into the vertebral plexus It is important to expose the bone before using the rongeur. It is important not to have anything but bone in the mouth of the rongeur when it is being used. Bleeding points from the diploe may be controlled with bone wax. Bleeding from the occipital sinus, extending down from the confluence of sinuses, may be stopped with the use of a silk ligature.

In *5* the posterior fossa and the upper portion of the spinal dura have been exposed The dotted line represents the incision in the dura. The dura may be incised as indicated so that it can be closed tightly if so desired at the completion of the operation. Such a dural incision allows an excellent exposure of the cerebellar lobes, cerebellopontine angles, the cephalic portion of the spinal cord, as well as the cisterna magna and the lower end of the fourth ventricle In making the incision, veins will be encountered from the occipital sinus and its tributaries at the foramen magnum. It is best to use clips for bleeding points rather than coagulation which causes dural shrinkage, making closure more difficult. The occipital sinus inferiorly may be obliterated by ligation. The occipital sinus extends to the transverse sinus These venous channels also bleed profusely and may be controlled by using silver clips


P
a
5



In the accompanying illustration a cystic astrocytoma of the cerebellum is shown. In *6* the occipital sinus in the median portion of the dura is shown tied with a silk suture. The dura is then stitched to the scalp superiorly. The spinal dura is also secured laterally for exposure. A cystic tumor mass is indicated in the right cerebellar lobe. A syringe is used to aspirate the contents of the cyst. After a specimen has been obtained, saline solution may be reinjected into the cystic cavity to prevent collapse of its walls.

In *7* the vessels extending toward the cyst are coagulated or clipped and the superior or external surface of the cyst structure is uncapped with the use of the electrocutting unit.

In *8* a mural nodule in the lateral portion of the cyst wall is shown. In *9* the mural nodule is excised with the electrocautery loop. In *10* the wall of the cystic tumor is carefully separated from the cerebellum and removed. This is possible in some cases when the wall can be delineated. Dissection by means of cottonoid at the end of a bayonet forceps is usually adequate. Excision of the mural lesion is necessary and may require careful search with lighted retractors.

After the conclusion of the excision the dura is closed with interrupted silk sutures. A tight closure is desirable. The muscles of the occiput and neck are approximated with catgut or silk sutures. The skin is approximated in layers with interrupted silk sutures.

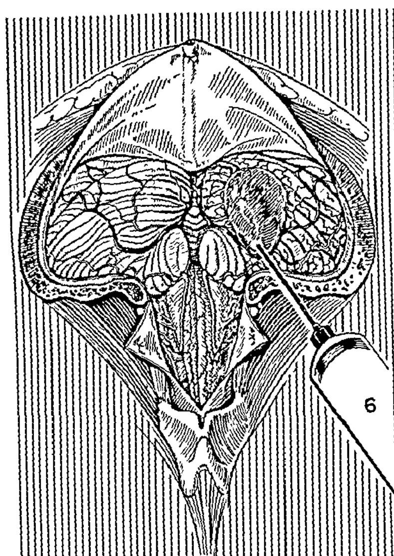
If the suboccipital craniectomy has been done through a midline incision it is not necessary to immobilize the head in slight hyperextension with adhesive strips applied over a dressing from the forehead to the back of the patient ("check-rein"). When the crossbow type of incision has been used such a dressing is advisable to prevent disruption of the horizontally sutured muscle layer.

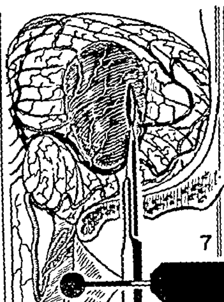
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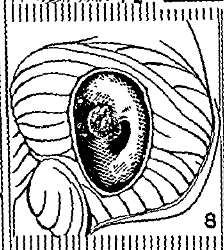
*The Lateral Sinus*

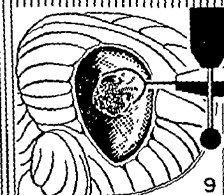
The lateral sinus on the right side is usually a continuation of the sagittal sinus, although at the confluence of sinuses there is usually a communication between the lateral sinus on the one and on the other side. The lateral sinuses extend laterally and forward to the petrosomastoid junction and then they curve medially and inferiorly to reach the jugular foramen. They end in the jugular bulb and the internal jugular vein on either side. The sigmoid sinus is that portion of the lateral sinus in juxtaposition with the mastoidopetrous junction The lateral sinuses receive a few inferior cerebral veins from the occipital portion of the hemisphere and a few superior cerebellar veins as well as the mastoid and condyloid emissary veins and the superior and inferior petrosal sinuses. The lateral sinuses begin at the internal occipital protuberance

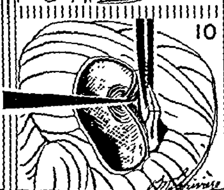
(*Continued on page 136*)




6 Cerebellar cyst being aspirated.

7. Cyst wall uncapped with cutting current.

8. Mural nodule located.

9. Excision of mural nodule.

10. Wall of cyst removed with cottonoid dissection.

## Posterior Fossa Exploration

*Exploration of the posterior fossa* can be accomplished with the patient in a prone position and the head in the cerebellar head rest. The upright position, with the patient sitting up and the head flexed forward, supported by the cerebellar head rest, is more advantageous. Such advantages include a clearer eye level view of the operative field. Adjustments in the view can be made by *raising or lowering the chair. Bleeding becomes less serious since* the venous pressure is lessened in the upright position and the bleeding which does occur flows distally without pooling. Disadvantages of circulatory collapse may be overcome by maintaining the blood volume throughout the operation. If necessary, the upright chair may be converted into a table. The aspiration of air through the deep *veins of the surgical* field has not caused complications.

The straight median incision has advantages over the horseshoe or crossbow type. These include ease of opening and a closure attended with fewer complications. The exposure is equally adequate. This incision used with the patient in the upright position has converted a prolonged and tedious operation into a more simplified one.

Before the cerebellar procedure begins, a ventricular tap is first done *through an occipitoparietal opening near the midline* by *placing an indwelling* flanged cannula into the ventricle. The cerebellar dura may be safely opened with or without a preliminary tap into the cerebellar hemispheres for a cyst. On opening the dura and suturing its reflected edge to the superior scalp border, the cerebellar lobes, tonsils and the pontine angle may be inspected. The cisterna magna may be found to be small or obliterated by descendent cerebellar lobes and tonsils; asymmetry of the tonsils may be present; one cerebellar lobe may be enlarged; the surface convolutions may be wider and flatter; fluctuation may be evident; *the vermis may be widened;* the color of the cerebellar folia may be of a yellowish tint, suggesting an underlying mass which is causing marked pressure; the cerebellar lobes may appear swollen, making retraction more difficult.

After permitting escape of fluid from the cistern, further inspection with *direct lighting must include a* view of both cerebellopontine angles, and the fourth ventricle. Palpation of the cerebellar lobes with a brain cannula may be employed, care being taken to avoid directing the cannula into the brain stem. The survey is completed by determining *the patency of the communi*cation of the lateral ventricles with the fourth ventricle by injecting a dilute indigo carmine solution into the tapped ventricle and observing its appearance at the fourth ventricle.

## Acoustic Neurinoma

The 19th century literature includes mainly postmortem rather than ante mortem cases of this posterior fossa neoplasm. In 1830 a report by Charles Bell[3] clearly identified an acoustic tumor Jean Cruveilhier reported a detailed clinical pathological account of this particular type of tumor.

In 1902 Hartmann identified this lesion as a tumor of the recessus acustico-cerebellaris. Thus, the term "recess tumor" was used in describing a mass in this locality. "Cerebellopontine angle" or "Kleinhirnbrueckenwinkel tumor" was suggested by Henneberg and Koch. The term "acoustic tumor" was preferred by Cushing[93] and it is obviously more descriptive of the lesion.

The history of the surgical treatment of acoustic tumors is filled with many early failures such as characterized the surgical approach to both intracerebellar and extracerebellar neoplasms at the beginning of the 20th century. The prevailing mortality for an incomplete operation at the hands of the most skilled surgeons ranged from 58 per cent by Horsley to 83.8 per cent by Krause as presented by Tooth[433] at the International Neurological Congress in 1913. Such failures have been attributed to several factors, including the limited exposure by a unilateral suboccipital craniectomy; the use of the finger in enucleating the neoplasm resulting in hemorrhage which could only be controlled by packing with resulting brain stem damage, and "operative haste". Early in the beginning of the 20th century a unilateral suboccipital craniectomy was employed by Horsley[331] and by Wolsey[459a] in one or two stages. Krause[269] in 1903 described a unilateral osteoplastic procedure done in two stages, and his name has thus been identified with the unilateral suboccipital exposures, regardless of the many modifications that followed. Usually, the early operations were done in two stages. Resection of the outer portion of the cerebellar lobe was recommended by Frazier[149] and Borchardt[27]. Cushing[75], in 1905, described a "bilateral exposure of the cerebellar hemispheres through a crossbow incision". This was stated to be "for the purpose of exploration and decompression for obvious subtentorial lesions not localized on one side or the other". It was used for all cerebellar tumors and adopted for the acoustic tumor. Its advantages included adequate exposure by "dislocation outward of the unaffected hemisphere and the avoidance of medullary compression by decompressing a pressure cone". Based on the results of cadaver dissection Frazier[149], in 1905, also recommended a bilateral exposure.

Cushing first employed an intracapsular rather than total removal of the acoustic tumors as had been attempted in the past, stating "I doubt very much, unless some more perfected method is devised, whether one of these lesions can with safety be totally enucleated".

Developments subsequently led to a return to the complete operation of extirpation. Dandy[93, 109] first, by a bilateral exposure and then a unilateral one, successfully demonstrated that this tumor was removable. Others have confirmed his experience.

## Unilateral suboccipital craniectomy for acoustic neurinoma

▶

In *1* the skin incision, an inverted L, is shown by the interrupted dashline. The solid black line represents the opening in the skull involving the squamous portion of the occipital bone on the left side, extending into the foramen magnum, as well as the removed portion of the posterior arch of the atlas on the left side. The dotted line represents the projected incision in the dura. The scalp incision paralleling the nuchal line is extended to the bone after cutting through the occipitalis muscle. All layers are reflected with the periosteal lining. The midline portion of the incision is extended through the midline areolar tissue, thus minimizing bleeding and muscle trauma. When the bone is exposed at the midline the muscles are reflected toward the left side with a stout periosteal elevator or chisel. Scissors may be used to cut the tendinous muscle attachments. Reflection of the muscles from the superior nuchal line, as well as the squamous portion of the occipital bone, is preferred. At the foramen magnum the posterior arch of the atlas and a portion of the axis are also exposed. The opening is now made in the skull *from the mastoid to just past the midline and inferiorly to the foramen* magnum A portion of the posterior arch of the atlas is also removed. The dura is now opened in a position shown by the dotted line in *1*.

In *2* the dura is stitched superiorly to expose the cerebellar lobe and covered over with a layer of moist cottonoid The presence of a tumor mass is now identified by carefully lifting the cerebellar lobe and exposing the cerebellopontine angle. Once a neoplasm has been identified beyond doubt, one may elect, as in *3*, to excise the lateral third of the cerebellar lobe to allow more room. The superficial vessels are clipped and cut, or coagulated and sectioned with the electrosurgical unit The lateral third of the cerebellum is then resected. Suction may be used to advantage in this excision.

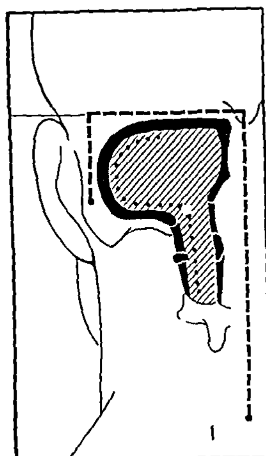
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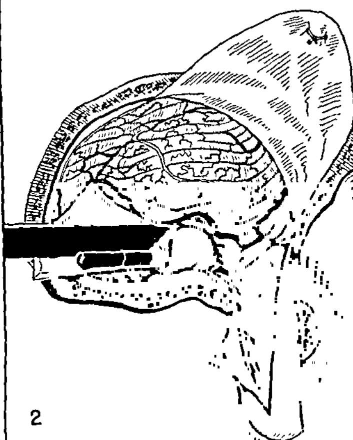
*The Lateral Sinus (concluded)*

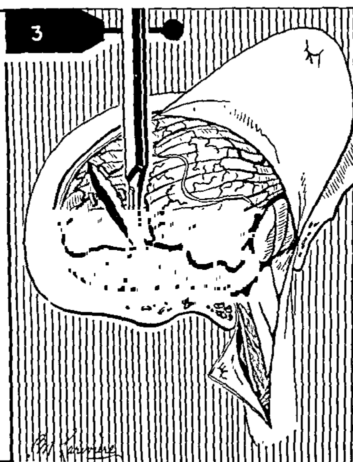
and they lie in the attached portion of the tentorium cerebelli posteriorly

Inferiorly, the lateral sinuses at the midline communicate with the occipital sinus which extends from the foramen magnum to the lateral sinus. At the foramen magnum the occipital sinus may have two tributaries extending from the foramen magnum and receiving many venous tributaries from around the foramen.

In bisecting the lateral sinus the veins from the inferior surface of the occipital lobe and the superior surface of the cerebellar lobe should be sought for and ligated In depressed fractures of the superior nuchal line neighborhood the possibility of a tear of the lateral sinus should be kept in mind A good exposure of the region is essential to control the bleeding of a torn lateral sinus




Head acutely flexed.

1. Interrupted line—skin incision pattern.
   Solid black—opening in the bone, including posterior arch of atlas.
   Dotted line—dural incision
2. Cerebellum elevated. Presence of acoustic tumor verified.
3. Surface vessels clipped or coagulated.
   Lateral third of cerebellum excised with electrocautery.

In *4* the acoustic tumor is visualized from the lateral aspect. Before the neoplasm itself is viewed a thin membranous cyst, containing spinal fluid, may first be encountered covering the neoplasm. In *5* it is visualized from the inferior aspect. The cerebellar lobe is covered with cottonoid before retraction is attempted. Gradually more exposure is obtained with deeper application of the cottonoid until the mass is in full view. When this point is reached then all cottonoid is removed and a fresh single layer of cottonoid is applied. Visualization of the tumor mass at its inferior aspect is important since the position of the 9th, 10th and 11th cranial nerves must be identified and injury avoided. A piece of cottonoid is placed over the 9th, 10th and 11th cranial nerves. For protection the position of the 7th cranial nerve should also be investigated. If the tumor is large it may extend into the tentorial opening from which it must be freed.

In *6* the tumor mass is now incised horizontally after coagulating any vessels that may be present in the capsule. Caution is required in employing electrocoagulation, particularly adjacent to the pons. Silver clips should be used when possible. With great care the contents within the capsule are removed with the use of a pituitary curette. The capsule must be gently treated to avoid tearing. This is shown in *7*. A pituitary forceps and scissors may be also used. Bleeding points may be coagulated or controlled with suction over cottonoid for a few minutes. In some cases it is possible to identify the 7th nerve and avoid injury by dissecting out the nerve. The position of the 7th nerve in the tumor may be identified with an electro-stimulator unit as dissection proceeds.

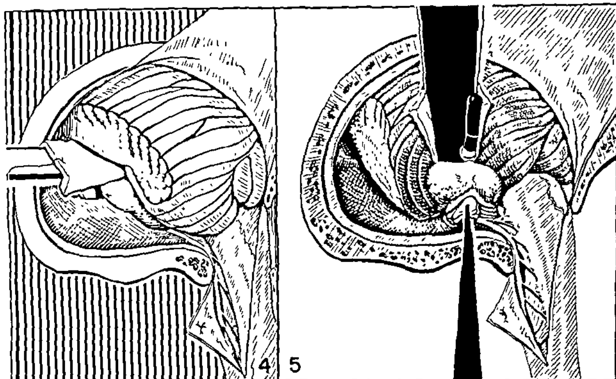
Avoidance of injury to the 10th cranial nerve is essential and this is accomplished by providing protection with a sheet of cottonoid placed over the 9th, 10th and 11th cranial nerves at the jugular foramen.

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*The Tentorium Cerebelli*

The tentorium cerebelli is a layer of dura which is elevated in the middle and it is lower toward its circumferential attachments. It supports the occipital lobes of the brain and also covers the superior surfaces of the cerebellum. There is a large opening anteriorly, the so-called incisura tentori, through which the cerebral peduncles are transmitted. Along its circumferential attachment to the occipital bone, it houses the transverse sinus on the so-called transverse ridge of the inner surface of the occipital bone. Along its attachment to the petrous bone, it houses the superior petrosal sinus. At the apex of the petrous bone, the dural tentorial border becomes attached to the anterior and posterior clinoid

*(Continued on page 142.)*




4. Tumor exposed laterally.
5. Tumor exposed inferiorly. Cottonoid placed on IX, X and XI cranial nerves near jugular foramen.

6
7

6 Capsule incised.
7. Fractional removal of tumor.

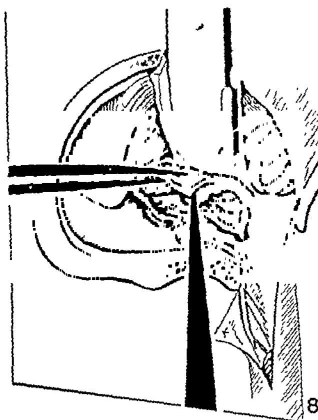
In *8*, after removal of most of the tumor piece-meal, the capsule is grasped and by careful dissection with cottonoid at the end of a bayonet forceps, it is gently separated from the surrounding tissues. Much care and patience are needed to accomplish this without injury to the brain stem. Bleeding points should be identified and clipped. The arterial supply is from the basilar and vertebral branches located on the medial aspect of the tumor and these are encountered as the capsule is freed. Venous connections are also medially situated, being branches from the petrosal vein, leading tributaries to the petrosal sinus. Coagulation current should be used extremely cautiously in this region.

In *9* almost all of the capsule has now been removed. The 9th, 10th and 11th nerves in the jugular foramen can be seen, as well as the internal auditory meatus. A portion of the 5th cranial nerve, as well as the 7th cranial nerve, may be seen in the background. Dissection of the capsule is often advantageously begun at the jugular foramen with the 9th and 10th nerves under continuous vision.

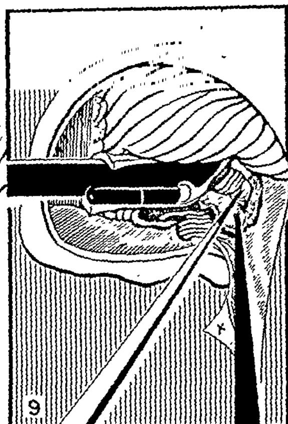
In *10* the usual deformity of the brain stem is shown. The impression produced by the tumor may be seen after the removal of the tumor. The various cranial nerves in the vicinity are relaxed because of elongation by the tumor growth. The 5th, as well as the 7th, may be injured during the removal of the tumor. The side of the brain stem in juxtaposition to the tumor may be softened. Additional damage must be avoided. The care of the internal acoustic meatus is important since many of these tumors begin to grow in the meatal canal before becoming intracranial neoplasms. A portion of the tumor can be removed without additional injury to the facial nerve in some cases. It is better to remove this tumor in its entirety and have facial paralysis, than to save the facial nerve and have remnants of tumor in the internal acoustic meatus or in the cerebellopontine angle.

In *11*, after complete hemostasis, the dura is now closed with interrupted silk A tight closure of all layers is made, although some prefer to use drainage

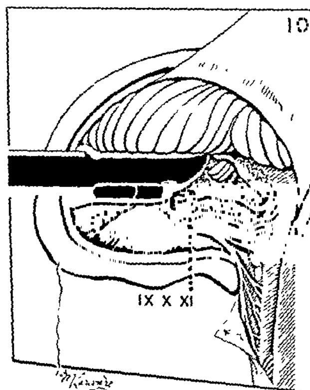
If the facial nerve has been sacrificed in the removal of an acoustic neurinoma, then a facial-spinal accessory or facial-hypoglossal anastomosis may be performed two to four weeks after the removal of the tumor. If a 5th nerve paralysis also exists the lid over the affected cornea may have to be closed by suture



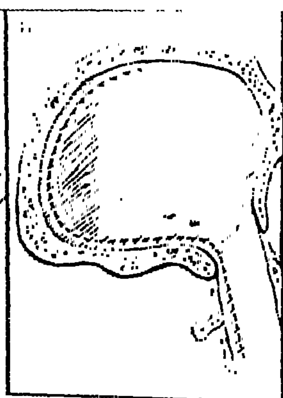

8 Dissection of the capsule with remaining tumor.




9. Portion of capsule near V nerve and brain stem being removed




10 Deformity of brain stem due to pressure from tumor IX, X, XI cranial nerves and jugular foramen.



11. *Dura closed tightly.*

## Removal of acoustic neurinoma after section of lateral sinus and incision of tentorium cerebelli

▶

This procedure is best performed with the patient in the sitting position under endotracheal anesthesia. The reversed hockeystick incision is shown in *1* by the dashline. Its upper limit is above the superior nuchal line, by 4 or 5 cm. The incision of the scalp is extended down to the bone in order to reflect the periosteal lining along with the muscle layer of the occiput and the neck. At the midline of the occiput and the neck the incision is extended through the midline areolar tissue, after the ligamentum nuchae has been incised. This facilitates the exposure of bone and minimizes bleeding.

In *1* the solid black line represents the opening in the skull. That portion of the skull above the lateral sinus is not removed until an angle tumor has been confirmed. The dotted line represents the opening in the dura which may be extended across the lateral sinus and into the dura covering the occipital portion of the cerebrum. The posterior arch of the atlas is removed in part.

In *2* the cerebellum has been exposed and the presence of an angle tumor verified. The opening in the skull has been extended upward above the lateral sinus. The position of the lateral sinus can be told by the color and bone is removed above this level by 2 to 3 cm. The dura has now been opened above the lateral sinus, exposing the occipital pole of the hemisphere. With the dura open over the cerebellum, as well as over the occipital pole of the hemisphere, the extent of the lateral sinus is identified. It is then doubly ligated and cut. Hemostasis should be complete. Cortical veins extending into the lateral sinus are coagulated. The latter is sectioned at a site midway between the mastoid and the confluence of sinuses.

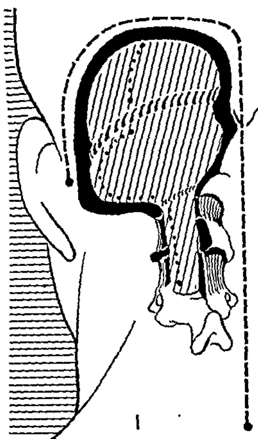
In *3* the tentorium cerebelli is being incised. As soon as this has been accomplished the cerebellar hemisphere may be mobilized with great ease. The tentorial incision is extended all the way to the incisura but not necessarily through the incisura. The cerebellar lobe, following section of the tentorium, is very easily mobilized and it is not necessary to excise its lateral third for more exposure.

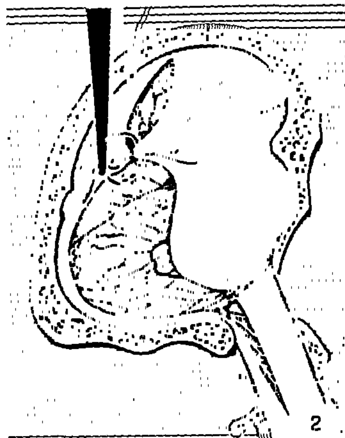
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*The Tentorium Cerebelli (concluded)*

processes. The falx cerebri is attached to the middle of its upper surface and where these two structures are united, they form the straight sinus.

The cerebellar falx is a small, dural evagination into the posterior cerebellar notch and it is attached to the posterior and inferior part of the tentorium at the midline. Inferiorly, this falx may divide into two smaller evaginations near the foramen magnum. The tentorium cerebelli is relatively avascular, except where the aforementioned venous sinuses form. After doubly ligating the lateral or transverse sinus, halfway between the confluence of sinuses and the mastoid region, one may section the tentorial lining with little or no bleeding all the way down to the incisura.

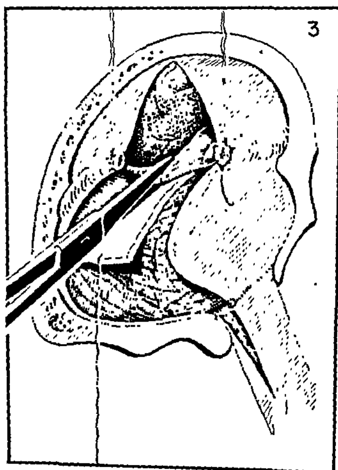



1. Interrupted line—skin incision.
   Solid black—craniectomy.
   Dotted line—dural incision over cerebellum and cerebrum across lateral sinus.

2. Lateral sinus doubly ligated and cut. Occipital pole well visualized.

3. Tentorium cerebelli cut toward the incisura.



In *4* the superior pole of the acoustic tumor is shown by gently retracting the cerebellar lobe downward and medially. The sectioning of the tentorium cerebelli makes mobilization of a large mass extremely easy; whereas without such a section it is most difficult.

In *5* the inferior extent of the acoustic tumor is shown by gently rotating the cerebellum upward and medially. The jugular foramen and the 9th, 10th and 11th cranial nerves are identified.

In *6* the area after removal of the tumor is shown, with the 5th, 7th, 9th, 10th, 11th, and 12th cranial nerves brought into view. The tumor has been removed by the fractional method previously described, followed by careful removal of the capsule, beginning from the region of the 9th, 10th and 11th cranial nerves A portion of the tumor in the internal acoustic meatus also has been removed.

The closure of the dura is shown and it is most important that the dura *is closed tightly. This is the reason why carefully planned incision of the* dura is necessary, making the closure easy.

The postoperative dressing in such a case does not necessitate unusual measures of immobilization of the head in relation to the neck and body, since the contralateral muscles of the neck are still intact.

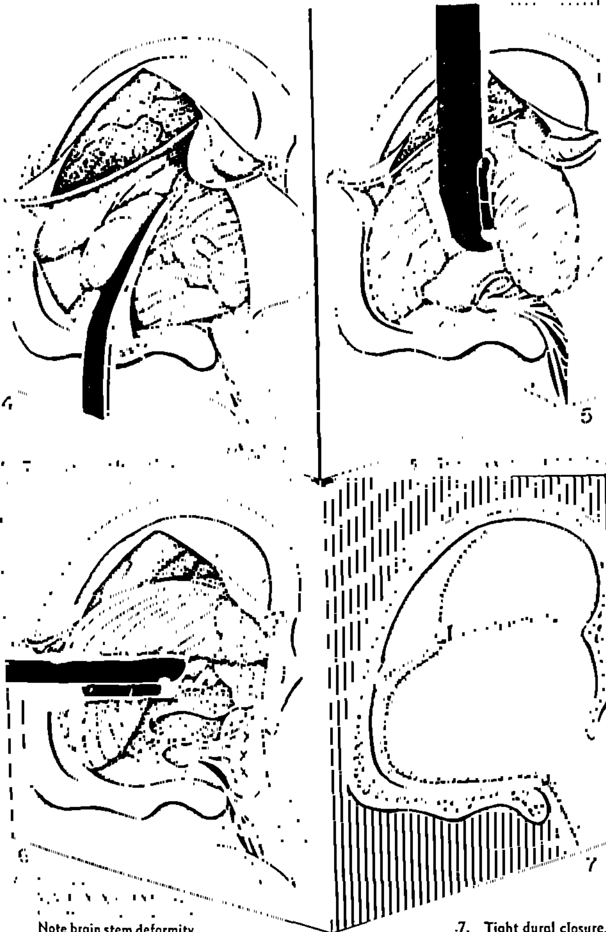
The method described for exposure of the occipital pole of the hemisphere and the cerebellum through a craniectomy is much simpler than a bone flap in the occipital area and an occipital craniectomy adjacently. Postoperatively only a very small area of bone defect is felt immediately along the superior nuchal line on the side of the operation.

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### *First Cervical Vertebra*

The first cervical vertebra is also called the atlas because it supports the globe of the head. It has no body and has no spinous process. It is divided into the anterior arch, the posterior arch and the lateral masses The anterior arch internally articulates with the odontoid process. Externally, it presents the anterior tubercle to which the longus colli muscle is attached. The posterior arch also has a tubercle externally. To it are attached the two rectus capitis posterior minor muscles The lateral mass consists of a superior articulating surface which articulates the condyle of the occipital bone and the inferior articulating process which articulates with the axis.

The transverse process, lateral to the articulating processes is traversed by the foramen transversarium. The atlantooccipital ligament is attached to the posterior arch and the atlantoaxial ligament connects the posterior arch of the atlas with the axis inferiorly. In many operations the posterior arch of the atlas is in part removed but care must be taken in the lateral exposure, since the vertebral artery may be injured The artery enters the cranial cavity between the occipital bone and the posterior arch of the atlas and extends to the anterolateral aspect of the brain stem.




Note brain stem deformity.

.7. Tight dural closure.

scalp and skin are closed in several layers. The 9th nerve section results in loss of taste over the posterior one third of the tongue on the ipsilateral side, and anesthesia of the soft palate, tonsillar area and base of the tongue.

With greater experience one may be able to do this operation with a smaller craniectomy opening at the squamous portion of the occipital bone. However, the procedure is simplified by adequate exposure.

This exposure may be done with the patient in the sitting-position, using endotracheal anesthesia. The same procedure may be used for section of the 5th cranial nerve in the posterior fossa, the 8th cranial nerve and for medullary tractotomy.

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*Position of the Fifth to the Eleventh Cranial Nerves in the Posterior Fossa*

The fifth cranial nerve consists of the sensory root and the motor root. The latter is very much smaller than the former and is anterior and medial to the sensory root. The motor root consists of a mesencephalic portion and a portion which innervates the masticatory muscles The mesencephalic root probably carries proprioceptive impulses and is a sensory component. The sensory root consists of fibers, the cell bodies of which are in the semilunar ganglion. These fibers enter the pons and divide into ascending and descending branches. The descending branches extend down to the medulla and the upper part of the cervical spinal cord and constitute the spinal root of the trigeminal nerve. The descending root of the trigeminal causes an outbulging on the posterior surface of the medulla third from the midline, the most medial outbulging being the gracilis, the next being the cuneate and the third being the spinal root of the trigeminal nerve. Tractotomy deals in section of this part of the trigeminal complex.

The facial and acoustic nerves as well as the nervus intermedius or the nerve of Wrisberg leave the cranial cavity through the internal acoustic meatus. The facial nerve is slightly anterior and somewhat superior to the acoustic nerve, the nerve of Wrisberg is in an intermediate position. A definite line of demarcation may be seen between the facial and the acoustic and it is a simple matter to separate these two nerves. In some specimens the nerve of Wrisberg is easily isolated, in others it seems to be fused with the facial nerve. The nerve of Wrisberg or the nervus intermedius is the sensory portion of the facial complex.

The acoustic nerve consists of the cochlear and the vestibular portions. At the cerebellopontine angle, the cochlear portion is lateral and the vestibular is medial The portion of the acoustic in juxtaposition to to the nervus intermedius is the vestibular portion of the nerve.

The ninth, tenth and the eleventh nerves pass out of the cranial cavity through the jugular foramen. These nerves are in a position posterior to the outgoing jugular vein. The ninth cranial nerve is in a separate dural opening anterior to the tenth cranial nerve. The tenth and the spinal accessory nerves are contained in the same dural lining but have separate arachnoid coverings at the jugular foramen. The jugular ganglion immediately on the outside of the jugular foramen is the sensory ganglion of the tenth cranial nerve The nodosal ganglion is a little more inferior and it receives the cranial portion of the spinal accessory nerve. The

A partial or complete section of the auditory nerve is occasionally used to relieve the vertigo or tinnitus aurium of intractable Ménière's disease. Ménière,[305] in 1861, related the condition of tinnitus associated with vertigo and hearing loss to a disturbance in the labyrinth on the affected side. Previously this condition had been described as cerebral apoplexy. The observation was subsequently made by Charcot that ultimate deafness resulted in cessation of the tinnitus and vertigo, thus presenting the possibility that section of the 8th nerve could cure a patient.

In 1898 Krause[2 9] sectioned the acoustic nerve for relief of tinnitus. In 1908 Frazier[152] performed the same procedure, although specifying that it was being done for vertigo.

It was not until years later, in 1924, that Dandy[103, 108, 110, 111] began a series of many operations upon the 8th cranial nerve in the treatment of so-called Ménière's disease. The entire 8th nerve was sectioned and the results were reported as satisfactory for the relief of both vertigo and tinnitus. Section of the vestibular portion with sparing of the cochlear part, was advised by McKenzie[302] in 1931. Thus, it was possible to preserve the auditory function. Further experience with section of the vestibular portion of the 8th nerve has indicated that although relief from vertigo is accomplished in a high percentage of patients, relief from tinnitus cannot be assured.

The exposure of the 8th cranial nerve and the 5th cranial nerve is by precisely the same route as that for the 9th cranial nerve. An adequate unilateral suboccipital craniectomy should be employed for cases in which the 5th cranial nerve is to be cut by the posterior approach. After opening the dura with a sickle-shaped incision the tonsil and the cerebellar lobe may be directly elevated until the jugular foramen is exposed. After extension of the dissection superiorly and anteriorly, the 7th and 8th cranial nerves may be seen extending into the internal auditory meatus. At times the small internal auditory artery may be immediately over the 7th and 8th cranial nerves. In such a case it may be necessary to coagulate this small arterial twig and section it.

For section of the 8th nerve, with the patient in the sitting position, one notes the presence of a line of cleavage between the 7th and 8th cranial nerves. This can be seen with ease and one can readily separate the 8th and 7th cranial nerves with a sharp dissector or the tip of a pointed knife. In

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spinal portion of the spinal accessory nerve is seen extending up from the upper four or five segments of the cervical cord toward the jugular foramen. It is an important landmark for the location of the jugular foramen.

some instances the nervus intermedius, or the nerve of Wrisberg, may be seen between the 7th and 8th nerves. The vestibular portion of the 8th nerve is toward the facial nerve. As shown in *5*, this may be cut and deafness avoided. In other cases, as shown in *6*, the entire nerve may be cut, particularly if the patient is already quite deaf. In *3* and *4* the separation of the 8th from the 7th cranial nerve and the cross-sectional view of the 7th nerve, the nervus intermedius and the two portions of the 8th nerve may be seen. Section of the nervus intermedius, the sensory division of the 7th, may be employed in geniculate neuralgia described by Ramsay Hunt. This is a rare affliction.

In *2* the position of the 5th, 7th, 8th and 9th cranial nerves is shown.

When section of the 5th cranial nerve is desired the patient's head is flexed more acutely than when the 9th or the 8th cranial nerves are to be sectioned. It is also advisable to have a wide craniectomy opening and a generous opening of the dura. Evacuation of the cerebrospinal fluid in the cisterna magna is important. To visualize the 5th cranial nerve, elevation of the cerebellar lobe more laterally and anteriorly is required than for viewing the internal auditory meatus. The 5th cranial nerve may be seen superior and medial to the 7th and 8th nerves extending into the internal acoustic meatus. Under full view the trigeminal root may be cut with sharp scissors or a knife. It should never be torn with a hook. The petrosal vein lies superior to the root and must be avoided.

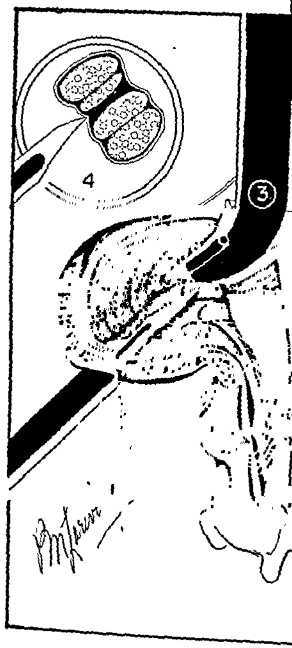
When both the 5th and 9th cranial nerves are to be sectioned, as well as the upper three or four posterior roots of the cervical area for intractable pain about the mouth and the side of the neck, the position of the head has to be changed in order to visualize the 9th cranial nerve, after section of the 5th nerve. It is moved from acute flexion to a more gentle flexion in order to gain exposure of the 9th cranial nerve with the tonsil and adjacent cerebellar lobe elevated with cottonoid protection

Section of the 5th root by the cerebellar route may be used for treating tic douloureux as suggested by Dandy[107] who reported among other advantages, the sparing of the motor root and the absence of facial paralysis. In some instances, as above mentioned, a combination of cranial nerves may require section in order to obtain a desirable result, such as 5th, 9th, portion of the 10th, and the upper cervical nerves The posterior approach is preferable to any other method for section of such a combination of nerves.

1. 5th, 7th, 8th, 9th, 10th, 11th cranial nerves exposed.
   With the head in a flexed position, 5th nerve sectioned.
2. Relative position of nerves
3. 7th and 8th separated.
4. 7th, nervus intermedius, vestibular and cochlear nerves from above downward
5. Vestibular section.
6. Acoustic nerve section.

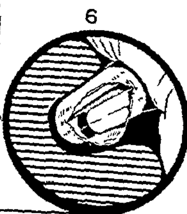










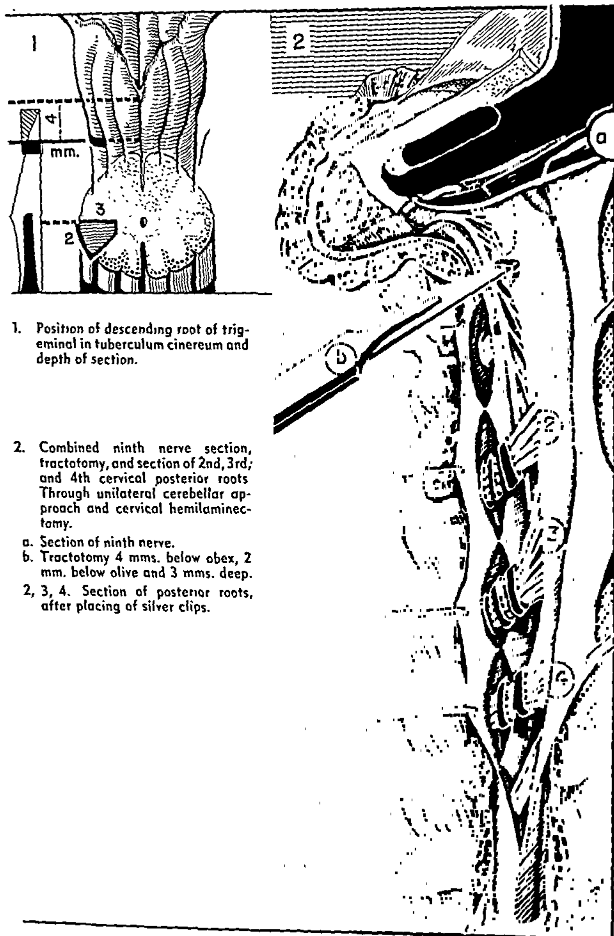
## Section of the ninth cranial nerve. Trigeminal tractotomy and cervical rhizotomy

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This combined operation may be adopted for patients with intractable pain due to cancer of the oral cavity and the side of the neck and face. An interruption of pain pathways of the trigeminal nerve was regarded by Sjöqvist[401, 407] in 1937 as possible by incising the descending root of the 5th nerve in the medulla. This was suggested in the treatment of trigeminal neuralgia. It offered the advantage that although pain was interrupted, *there was preservation of touch sensation. By means of a suboccipital crani*ectomy with exposure of the cerebellum, the fourth ventricle and the medulla, at a point dorsal to the lowest vagus fibers, and 8 to 10 mm. superior to the obex of the fourth ventricle, Sjöqvist suggested an incision 3 or 4 mm. in width and depth in the medulla. Correction of the point of incision in the medulla was made by Grant and Weinberger who avoided cerebellar complications by placing the incision 4 mm. below the obex. The use of this procedure for trigeminal neuralgia, although theoretically having advantages in view of the sparing of touch sensation, has in practice proven to be an uncertain one.

*The operation shown is that of a unilateral suboccipital craniectomy with* a hemilaminectomy in the upper cervical region. Such an approach is accomplished with the patient in the sitting position under endotracheal anesthesia. Through a midline incision, beginning just above the external occipital protuberance and extending down to the 5th or 6th cervical spinous process, the skin, subcutaneous tissue, and the ligamentum nuchae are incised, the trapezius muscle is separated and is retracted with the semispinalis capitis Following this the splenius cervicis, the longissimus cervicis, and the multifidus muscles are exposed and are scraped off the spinous processes and laminae of the upper four cervical vertebrae. At the level of the *1st and 2nd cervical vertebrae the rectus posterior major and the rectus* posterior minor are also stripped from these vertebrae respectively. The base of the skull is exposed by reflecting muscles off the squamous portion of the occipital bone on the side of the desired section. The craniectomy is performed in the occipital area with a good exposure of the inferior and lateral regions near the foramen magnum. The laminae of the upper four cervical vertebrae are removed. The dura is opened in the spinal portion *and the incision is extended upward into the cranial region in the form of a* sickle

In *1* the position of the descending root of the trigeminal in the tuberculum cinereum is shown at the level of the section. This is about 4 mm. below the tip of the obex and 2 mm. below the olive The incision is 3 mm. in depth




1. Position of descending root of trigeminal in tuberculum cinereum and depth of section.

2. Combined ninth nerve section, tractotomy, and section of 2nd, 3rd, and 4th cervical posterior roots Through unilateral cerebellar approach and cervical hemilaminectomy.
   a. Section of ninth nerve.
   b. Tractotomy 4 mms. below obex, 2 mm. below olive and 3 mms. deep.
   2, 3, 4. Section of posterior roots, after placing of silver clips.

In *2* the left occipital craniectomy and the left cervical hemilaminectomy has been completed. With care the cerebellar lobe is elevated and the 9th cranial nerve is visualized, separated and cut, as shown at *a*. At *b* 3 mm. of the exposed sharp end of the knife is thrust into the descending root of the trigeminal with the level at about 4 mm. below the tip of the obex. Lower down *2*, *3* and *4* denote the position of the posterior spinal nerve roots which may be sectioned following the application of silver clips.

At the completion of this procedure the dura is closed tightly over the cerebellum, as well as in the spinal canal. The muscles are sutured at the midline after hemostasis. The ligamentum nuchae is sutured followed by approximation of the subcutaneous tissues and the skin and scalp with interrupted silk sutures.

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### *Occipital Bone*

The occipital bone consists of the squamous portion, the basilar portion which is anterior to the foramen magnum and the lateral portion which is lateral to the foramen. The squamous portion of the occipital extends from mastoid to mastoid and from the foramen magnum to a little above the highest nuchal line. On its external surface is the external occipital protuberance in the midline and the superior nuchal line extending laterally from the protuberance toward the mastoid. These can be felt with ease. The inferior nuchal line which is a prominence in the bony surface half way between the superior nuchal line and the foramen magnum may be seen in the operating room in some patients. The median nuchal line or the prominence extending between the middle of the foramen magnum and the external occipital protuberance is also seen in the operating room. On the internal surface of the occipital squama one notes a transverse prominence for the attachment of the transverse sinus on either side of the internal occipital protuberance. Another prominence extending in a median position from the internal occipital protuberance to the foramen magnum is for the occipital sinus. The occipital bone lateral to the foramen magnum presents the condyloid canal and the occipital condyle for articulation with the atlas on either side of the foramen. The basilar process of the occipital, a quadrilateral piece of bone anterior to the foramen magnum, articulates with the sphenoid body anteriorly. The medulla oblongata is found on its internal surface

In doing a suboccipital craniectomy the muscles separated from the occipital squami include the trapezius, the semispinalis capitis and the rectus capitis posterior minor from the superior nuchal line down to the foramen magnum. In a more lateral exposure the rectus capitis posterior major and the obliquus superior as well as a portion of the occipitalis and the splenius capitis may also be separated.

## Hydrocephalus

The study of ventricular anatomy and communications began with the work of Magendie, Luschka, and Monro. Further observations by Key and Retzius, Dandy and Blackfan, Weed and others, revealed the importance of the choroid plexus as a source of the cerebrospinal fluid, and suggested that absorption was related to arachnoidal villi and the venous system of the subarachnoid space. It has been shown that there are two main classes of hydrocephalus, the communicating and the noncommunicating or obstructive types. Partial obstruction also may occur.

Treatment of the communicating type of hydrocephalus has been accomplished with many procedures which direct the cerebrospinal fluid into suitable channels for absorption Tubes or cannulae of one form or another have been placed in the ventricle and allowed to channel the ventricular fluid into the subdural space and under the pericranium, according to Keen[253] and Krause and Heymann. Other routes were used to direct the cerebrospinal fluid flow into the longitudinal sinus, the jugular vein, and the pleural cavity (Payr). The fluid within the spinal subarachnoid space has also been communicated with such structures as the peritoneum and retroperitoneal tissue (Cushing[74]), intestine (Heile[203]), the kidney pelvis (Heile[204]), and the ureter.[204,300] More recently Nosik has communicated the ventricular system with the middle ear, permitting flow of fluid via the eustachian tube into the oral pharynx. Various techniques for the removal of the choroid plexus, attempting a reduction of cerebrospinal fluid production, have been used and reported by Dandy[93], Putnam and Scarff.

In cases of obstructive or noncommunicating hydrocephalus, two surgical procedures, which are still employed, are those of third ventriculostomy and ventriculocisternal intubation (Torkildsen). Such operations are performed only in those cases of obstructed hydrocephalus which are not amenable to treatment by attack upon the cause of the obstruction.

The third ventriculostomy has the intent of shunting the cerebrospinal fluid from the third ventricle into the cisterna interpeduncularis and is employed in certain noncommunicating hydrocephalus cases. The procedure was first suggested by Dandy[95] in 1922 and later Stookey and Scarff helped to perfect it. Its disadvantages involve the closure of the stoma which is made in the bulging ventricular floor. This method has been found to be satisfactory, in instances of obstruction in the region of the aqueduct of Sylvius and the fourth ventricle. In infancy it may be a worthwhile procedure in some patients with atresia of the aqueduct of Sylvius. In other cases arachnoiditis about the fourth ventricle, involving the foramina of Magendie and Luschka, may be treated by this procedure or by ventriculocisternal intubation.

In *1* a diagram of the ventriculo-cisternal intubation is shown. A tube (rubber catheter No. 8 or 10) extends from the body of the ventricle into the cisterna magna and the subarachnoid space of the occipitospinal junction.

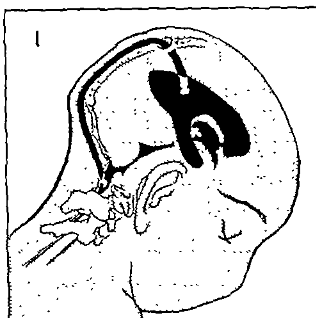
In *2* the position of the trephine opening is shown in *a*. The opening at the occipitospinal junction is shown at *b*. At *a*, through a skin incision 8 cm. above the occipital protuberance, and 3 cm. from the midline, a trephine opening is made. The catheter is introduced into the lateral ventricle after first identifying the position of the ventricle with a brain cannula. The ventricles in such cases are enlarged and readily tapped. A No. 8 or No. 10 catheter is used for this purpose. A Steinmann pin or a similar piece of wire of the proper dimension and thickness may be used as a stilette for the catheter when the latter is introduced into the ventricle. The end of the tube should be cut crosswise and there should be two small openings on either side as shown in *a*. The free escape of cerebrospinal fluid is not allowed when the rubber tube is introduced, so that patency of flow may be established at the completion of the procedure.

At *b* operative exposure of the cisterna magna is partly shown. Through a midline incision, from the external occipital protuberance to the 3rd or 4th cervical spinous process, the posterior arch of the atlas and the bone about the foramen magnum are exposed, after reflecting the muscles away from these regions and retracting them with self-retaining retractors. By remaining in the midline, bleeding will be minimal. Branches of the thyrocervical trunk may be encountered. The spinous process of the second cervical may interfere with proper exposure. If so it should be trimmed down when necessary. After the posterior arch of the atlas is removed the dura of the spinal canal is seen. A portion of the rim of the foramen magnum is then removed with a Kerrison rongeur. If it is also desirable to explore the posterior fossa at the same time a more adequate exposure of the squamous portion of the occipital bone bilaterally is obtained by an extended incision, separation and retraction of the muscles from the base of the skull.

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*Second Cervical Vertebra*

The second cervical vertebra is called the axis because the head rotates about it supported by the atlas. It has a body from the superior surface of which extends the odontoid process which articulates with the anterior arch of the atlas. Its spinous process ends in a bifid termination. The rectus capitis posterior major and the obliquus inferior are both attached to the spinous process of the second cervical vertebra. Inferiorly, the semispinalis extends to it and on the side of the spinous processes the multifidus muscle is attached. Between the superior and inferior articulating surfaces is the transverse process traversed by the foramen transversarium.




1 Ventriculo-cisternal intubation.

2a. Occipital burr hole on the right side, made 8 cm. above the external occipital protuberance and 3 cm. from the midline.

b. Cisterna magna exposed at foramen magnum.



In *3* the scalp is undermined from the trephine opening to the opening at the occipitocervical junction. This is accomplished by using scissors as shown in the diagram. The undermining should be at the periosteal layer.

In *4* the rubber tube has been introduced into the lateral ventricle. After removal of the stilette the tube is drawn via the undermined scalp into the region of the occipitocervical junction. In *4* at *a* the patency of the tube between the points *a* and *b* is established by obstructing the catheter between the thumb and index finger of the right hand and injecting fluid into the tube and noting its escape at *b*. At *c* the opening in the dura is shown. This opening extends through the arachnoid, allowing the catheter which is enclosed by the dural sac to rest in the subarachnoid cavity.

In *6* the patency of the tube from the ventricle into the occipitocervical area is established by injecting and withdrawing fluid from the ventricular cavity after finger obstruction of the lower end of the catheter, as shown in this figure.

The lower end of the catheter is trimmed to the desired length and small openings are made through the lumen of the catheter on either side of the long axis of the tube. About 1 cm. of the catheter end is secured to the dura and arachnoid by silk sutures, as shown in *5* It is important to have the end of the tube in the subarachnoid cavity. This is followed by suture of the remaining dura for a water tight closure. The portion of the rubber tube extending into the ventricle, through the trephine opening in the parieto-occipital region, is inspected and any excess tubing is gently extended toward the ventricle. The dura about the tube in this region may be sutured, if desired, or if the dura has been widely opened, closure of the skin is made in layers in this region and in the occipitospinal area. In the latter region the muscles are first approximated and sutured at the midline.

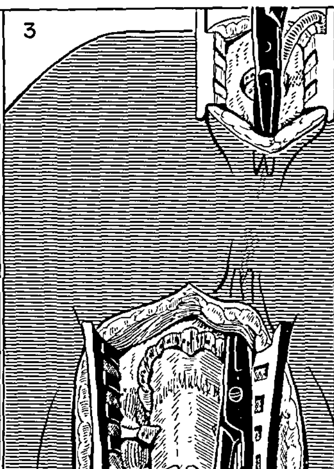
Particularly with third ventricle and midbrain tumors there may be a tendency toward the collection of fluid about the tube route thus producing a fluctuating area in this region. It is not necessary to aspirate this fluid. It absorbs eventually, particularly if deep x-ray therapy is also used to attack the tumor. It is obvious that the presence of unexplained increases in temperature, associated with such a fluctuating area, should be investigated.

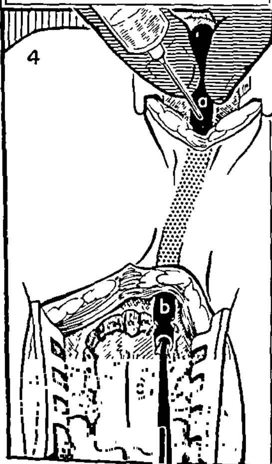
3. Skin undermined for passage of catheter.

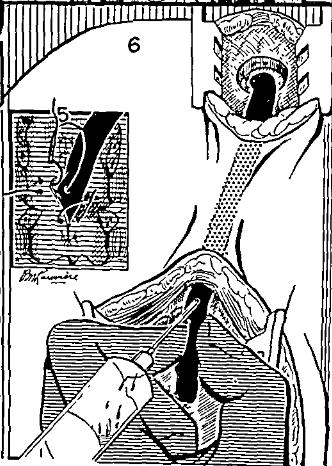
4. Patency of tube tested inferiorly. Compression with fingers at a Saline injected and obtained at b Dural incision at c.

5. Suture of rubber tube to underside of of dura and arachnoid lining.

6. Patency of tube tested superiorly. Compression with fingers at the lower end of tube. Saline injected into and evacuated from ventricle.



## Trigeminal Neuralgia

Section of the trigeminal root for tic douloureux and for the intractable pain from cancer involving the face and mouth within the confines of the trigeminal complex is a standardized procedure. The painful affliction of the face, termed trigeminal neuralgia and trifacial neuralgia, was named tic douloureux by Nicolus André in 1756. Fothergill, in 1773, described the clinical features of this condition and his name remains linked to this disease. Although the characteristic pain came to be clearly identified, both its cause and mediation remained obscure. It was not until the work of Magendie[294] and Bell[21] that the trigeminal nerve was recognized as the involved structure rather than the facial nerve which had previously been sectioned without relief of symptoms.

In the middle of the 19th century, attempts were made to section the peripheral branches of the trigeminal nerve with temporary benefit. At the end of that century, in 1884, Mears of Philadelphia suggested removing the gasserian ganglion by an extracranial route. The first successful operation is stated to have been done by Rose in 1890, and repeated in 1891, by an extracranial pterygoid route. Frazier[153] recorded Horsley's experience in 1891 "in a case in which failing to remove the ganglion he avulsed the sensory root, the patient dying of shock". Horsley[234] used a temporal intracranial approach. This approach became a favored route for operating upon the gasserian ganglion and was used by Hartley[198] and Krause[2,6], and their joint names identified this approach in contradistinction to the extracranial routes. Modifications of the temporal intracranial approach included the "infratemporal route" of Kocher[2 3] and Cushing[71], the zygomatic basal route of Doyen[124], and the auriculotemporal approach of Frazier. The present method described is a modification of the Frazier[153 154] technique by Adson[3].

Important observations by Spiller and Frazier standardized the treatment of trigeminal neuralgia. Spiller demonstrated that preganglionic section of the sensory root did not allow regeneration of the cut fibers. Frazier proved that this procedure was actually easier than removal of the gasserian ganglion Other improvements in the operation included a subtotal root section, sparing the ophthalmic fibers in the upper portion of the root and also sparing the motor branch when possible.

### *Temporal Fascia*

This fascia covers the temporal muscle It is a single layer of tough, fibrous lining, which is attached to the entire extent of the superior temporal line, but below, where it becomes attached to the zygomatic arch, it divides into two layers, one layer being inserted on the lateral aspect of the zygomatic arch, and the other is inserted on the medial aspect of this bone On its deeper surface, the temporal fascia affords attachment to the superficial fibers of the temporal muscle The temporal fascia is about 20 cm anteroposteriorly and 15 cm superoinferiorly and can be

used to advantage for repair of dural defects, such as with cerebrospinal fluid rhinorrhea. It is easily obtained and obviates the necessity of a second operation, such as may be indicated if a fascia lata trans plant is to be obtained. On its superficial surface, the anterior and superior auricular muscles are attached. In many instances, these muscles may be poorly formed or absent.

### *Temporal Muscle*

The temporal muscle is important in neurosurgery. It is a broad structure with the posterior fibers radiating horizontally forward and downward, the middle fibers radiating downward and forward, whereas, the anterior fibers extend vertically downward. It arises from the bone of the temporal fossa and the deep surface of the temporal fascia. The fibers converge into a tendinous structure which is inserted into the superior, medial and anterior surfaces of the coronoid process of the mandible. A vertical incision in front of the ear and above the zygomatic arch, will cut many of the fibers of the temporal muscle transversely. A slanting incision extending upward and backward from the zygomatic arch will tend to bisect the fibers along their length.

### *The Greater Superficial Petrosal Nerve*

The greater superficial petrosal nerve arises from the geniculate ganglion and supplies sensory fibers to the mucous membrane of the soft palate and preganglionic fibers to the sphenopalatine ganglion. It enters the cranial cavity through the hiatus of the facial canal and then courses in a depression on the anterior surface of the petrous portion of the temporal bone and extends forward and medially to a position behind the trigeminal ganglion and enters the foramen lacerum. Here it is joined by the deep petrosal nerve which has its origin from the sympathetic plexus of the internal carotid artery. The two together form the nerve of the pterygoid canal and this nerve ends in the sphenopalatine ganglion.

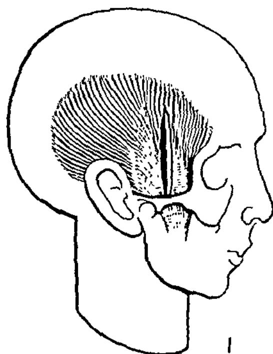
The greater superficial petrosal nerve is of surgical significance. Its manipulation during trigeminal rhizotomy results in a peripheral facial paralysis. Its section usually results in a dry mucosal lining of the nose on the affected side. It controls the lacrimal glands and its section is helpful in the treatment of bullous keratitis.

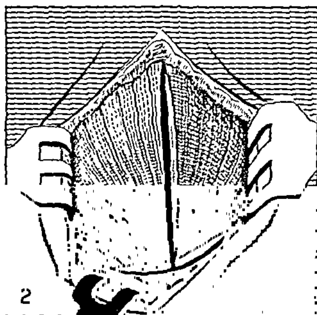
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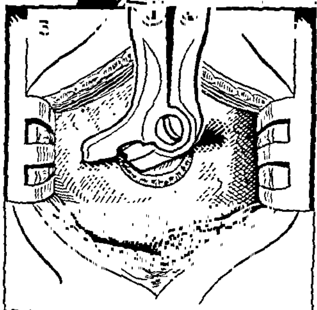
In *1*, with the patient in a sitting position, the site of the scalp and temporal incision are shown The incision, about 3 or 4 inches long, extends from the zygomatic arch upward about 1½ inches in front of the ear. This incision placed somewhat anteriorly is preferable to an incision placed closer to the ear since there is less bleeding. Only temporal artery branches are involved. Some of the temporal muscle fibers are obliquely cut in this incision. The attachment of the temporal fascia and muscle to the zygomatic arch is also sectioned as shown in *2*. Exposure of the zygomaticotemporal junction facilitates the exposure of the floor of the middle fossa. After making an opening in the skull with a perforator and a Hudson burr, the dura is separated from bone before extending the craniectomy with a rongeur. The dura in some patients is thin and may tear with ease. An opening 4 to 5 cm. is made with extension of the opening inferiorly to the zygomaticotemporal junction. The temporal opening reaches well inferiorly to allow good visualization of the base.

In *4* the dura of the base of the middle fossa is separated from the floor, avoiding tearing. Any fixed points are freed by sharp dissection. Dural separation brings the middle meningeal depression in the bone within view. The opening of the foramen spinosum is then seen as the dissection proceeds.

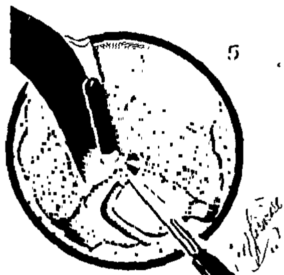
As shown in *5* the dura of the base of the floor of the middle fossa is carefully separated until the foramen spinosum is visualized. Lighted retractors are advantageous for proper visualization of the region. The foramen spinosum may now be plugged either with a cotton pledget or a small piece of wooden applicator, sharpened to a point for insertion into the foramen. After the foramen has been plugged the middle meningeal artery is cut with a sharp knife. The distal end of the artery may require coagulation or the use of a silver clip.

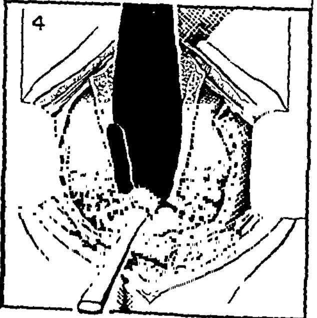



1. Position of skin and temporal incision.
2. *Temporal muscle incised.*
3. Burr hole enlarged.
4. Craniectomy extended to the base and dura stripped from skull.
5. Dural sac retracted.
   Foramen spinosum located. Applicator or cotton plug inserted into foramen. Middle meningeal artery cut.

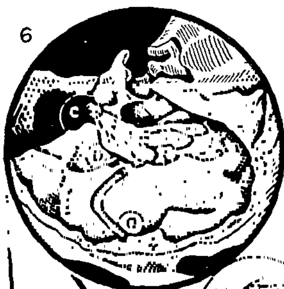


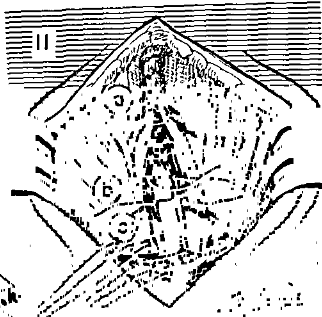



In *6* the anatomy of the base of the skull and the middle fossa is shown. At *a* the middle meningeal groove and foramen spinosum are noted. At *b* one sees the greater superficial petrosal nerve which disappears on the posterior aspect of the ganglion of the trigeminal. The foramen ovale and the foramen rotundum are seen, as well as the ophthalmic branch which extends to the superior orbital fissure. The ganglion and root may be viewed immediately lateral to the pituitary fossa and the cavernous sinus at *c*.

In *7* an important step of the dissection is shown. After the foramen spinosum is plugged and the middle meningeal artery sectioned with a pointed knife, the region of the foramen ovale is viewed and the dura propria of the third division of the trigeminal nerve separated from the dural covering of the brain. In the insert at *a* the third division of the trigeminal nerve is diagramed. With a sharp dissector the dural covering is carefully separated from this division, superiorly, anteriorly and posteriorly. As the dura is separated anteriorly the junction of the third and second divisions is first visualized. Later, the second division comes into view. For good exposure part of the second division may be freed, although this may result in bleeding from small dural veins. Gradually dissection is extended more posteriorly, thus exposing the ganglion and root as shown in *8* and *9*. In separating the dura from the ganglion and root, the dural adhesions to bone are sharply cut to avoid traction upon the greater superficial petrosal nerve It is this manipulation that may result in traction upon the greater superficial petrosal nerve and the geniculate ganglion. A facial paralysis may occur immediately or one or two days after the rhizotomy. The dura propria of the ganglion and root is now incised as shown in *8*. The incision should be made as close to the posterior termination of the ganglion as possible for subtotal section. When this is done and the propria is incised, there is usually a pulsating flow of cerebrospinal fluid in which the root fibers are bathed. The fibers are lifted with a hook and cut with sharp scissors This portion of the procedure is painful if the operation is being done under local anesthesia. Usually intravenous pentothal anesthesia is begun when the ganglion is being approached, although local infiltration of the ganglion may be used. After the fibers are carefully inspected the motor root may be recognized by its different texture, direction and size. Usually there is a single bundle but in some instances there may be two smaller bundles Deeper sensory root fibers should not be mistaken for the motor root. Such a mistake will result in incomplete denervation of the face with continuation of the pain.

Before closure is begun the base of the skull is inspected for bleeding. Neck compression may be used to confirm hemostasis. Gelfoam may be employed in small quantities. The dural sac may be filled with 10 to 20 cc. of saline solution which eliminates the "dead space" in the middle fossa by bulging of the dural sac toward the base In *11* the closure of the temporal

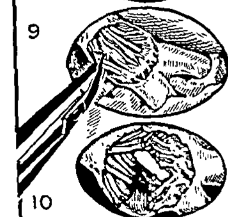









[illegible]

cleavage between temporal dura and nerve.

8. Second and third divisions, ganglion and root exposed.

9. Root exposed Bundles held up with hook cut with scissors.

   Ophthalmic root fibers seen crossing upward.

10. Motor root identified.

    Ophthalmic fibers saved.

11 Layer closure of muscle and temporal fascia.

   Note stitching of muscle at zygomatic arch neighborhood.

muscle and fascia is shown. As shown in *c* sutures are used in the temporal muscle and fascia at the zygomatic arch. The muscle is approximated with interrupted silk sutures as shown at *b*. At *a* the temporal fascia is also approximated with interrupted silk sutures. Usually drains are not necessary. One may use them for greater security and remove them within eighteen hours. The subcutaneous tissue and skin are closed with interrupted silk sutures.

If a total root section has been done it may be necessary to have the patient wear goggles to protect the eye. If facial paralysis results from the operative procedure it is best to perform a tarsorrhaphy, particularly if total section has been done.

If there is return of pain in the patient with subtotal section of the sensory root, above the area of denervation, one of two procedures may be used for further attack upon the trigeminal root. It may be cut by the posterior fossa approach, or section may be obtained by the intradural approach of Wilkins. By this method the temporal lobe is carefully elevated after opening the dura. The position of the ganglion and root is identified lateral to the pituitary fossa and the cavernous sinus. The dura is carefully incised, bringing into view the sensory root fibers which may be sectioned in their entirety.

# Head Injury

## Historical

INJURIES of the head have attracted the attention of healers since antiquity. The first written record of the surgical management of head injury is found in the Edwin Smith manuscript which has been translated by Professor Breasted. The management of head injuries as carried out by the ancient Egyptians is reported in some detail. Unlike other anthropological studies of historic races, study of early Egyptians has uncovered very few trephined skulls, according to Breasted and Stewart.

The writings of Hippocrates include a classification of fractures of the skull and details concerning the operative management of fracture. Fracture lines in the skull were exposed and identified by the use of a dye. The skull was trephined by incompletely removing the inner layer of the bone, expecting that this portion would subsequently be extruded. The Arabians, who preserved the Greek concepts which ultimately were transmitted to Italy by the monk Constantine, are responsible for our knowledge of early Greek practice. Such translations of medical practice stimulated the development of the Salerno School of Medicine. The treatment of cranial wounds with fragmentation of bone and various techniques of removal of bone fragments by a multiplicity of methods were the main themes of discussion. Wounds of the brain were not a problem since they were considered inoperable lesions.

The introduction of gunpowder by the English in 1346 presented a new surgical problem since intracranial wounds were commonly encountered. It was at first felt that all such gunshot wounds were "not only contused and burnt (requiring moist applications) but also poisoned by the powder (requiring desiccation) and hence difficult to cure". The wounds in general were early treated by the introduction of boiling elder oil or actual cautery.

It was not until the 16th century that a departure from these methods took place. Ambrose Paré, a leading surgeon of the Renaissance and "founder of military surgery as a science and art", discontinued the early practices, merely dressing wounds after applying a "digestive". Maggi of Italy supported the doctrines of Paré, in a published treatise on gunshot

wounds. Botallus and Fallopius "at once embraced the views of these nent masters" and Wurz of Germany, in about 1576, wrote agains employment of too complicated instruments for the extraction of ball deprecated trephining for depressed gunshot fractures of the skull. I 16th century Botallus described foreign bodies in the brain. Cerebra scess complicating foreign bodies in the brain was recognized but wa drained "even though it was recognized that death would result by expe treatment". Opinions were confused as to the wisdom of removing fragments from fractured skulls. It was "believed wise to bore if fissu the skull was present". Dyes were used to detect the discontinuity o skull, a practice employed in the Hippocratic era as previously mentio

Baron Larry presented rational methods for handling cranial wounds result of his experiences in the Napoleonic campaign in Russia, Gern and France. He reported that "in a wound of the head accompanied l fracture of the cranium, should the fragments of bone be displaced driven internally so as to injure the brain and dura mater, the trephi indispensable. When the foreign body which has caused the wound is closed between the pieces of bone and has penetrated into the interio the cranium, the case is again one which demands the application of trephine. Finally, when the surgeon is assured of the existence of eff fluid into the cranium, this instrument is also indicated". He believed operation should be performed early, recognizing that "inflammatio generally established in the meninges after the first twenty-four h succeeding the occurrence of the injury". Guthrie held a similar view s scribing to operative treatment based upon observations made in the I insular War of 1815. Hennen emphasized the importance of the trephine compression without fracture. "Where there is no wound the case beco dubious and we are reduced to act on probability founded upon gesture the patient, his sensibility of pain upon pressing a particular spot, or may be guided by what the French surgeon placed much dependence viz.; the existence of paralysis which is most commonly on the side of body opposite to the compressed portion of the brain"

Later, in the 19th century, a period of conservatism developed, trephine falling into disuse. Stromeyer, a German authority, in his Pr ciples of Military Surgery, stated that he had abandoned the practice trephining which he had advocated earlier A suggestion was even made Neudorser[334] that the trephine be excluded from the armamentarium the army surgeons.

In this period, important experimental concepts were developing co cerning injuries to the skull itself Aran, in 1844, described the "irradiatio theory of skull fractures He stated that fracture of the vault from an i pact on the vertex reached the base through the shortest possible rout implying that the fracture started at the point of impact Von Brüns,

1854, showed that the skull might be compressed from side to side resulting in a shortening of its side to side diameter, at the same time that the antero-posterior diameter was made somewhat longer. Pressure applied along one diameter would result in tearing apart forces in the portion of the skull at right angles to the direction of the force. Félizet, in 1873, reported that fractures result when an impact flattens out the curved surface of the skull. The fracture then is guided by the presence of buttresses, concerning which he made a classical description. Rawling, in 1905, suggested that the fractures of the base of the skull were produced by the force of the blow splitting the skull in a manner similar to that of a hatchet splitting a board through its grain. In general, until recently, it has been believed that linear fractures were the result of a generalized deformation of the skull due to a blow, while depressed fractures resulted from local inbending.

The effect of blows upon the head in relationship to the intracranial contents gained slower recognition. The term "cerebral commotion" was used to describe a damaged brain which might or might not survive the injury. Littre's report of a head injury death in 1705 focused interest upon the subject of concussion which has since led to a variety of theoretical and experimental concepts. Gamma, in 1835, studied comparable mass movements of the brain by simulated structures, using threads in a jelly. The work of Duret[127], Koch and Feline, and Polis furnished important basic concepts which could be correlated with clinical observations. An understanding of the pathophysiology of compression as distinguished from concussion was an important development at the end of the 19th century.

With a better understanding of both the skull and brain damage produced by injury, more rational treatment was employed. The trephine again came into use as also did more extensive operations such as the subtemporal decompression employed for relieving increased intracranial pressure associated with brain injury. Methods of dehydration by using hypertonic parenteral solutions and lumbar puncture became favored methods of treatment until recent times.

Modern research and the experience of two world wars has accumulated new knowledge that has refined and standardized the treatment of skull and brain injuries. In summary, this knowledge indicates that when the skull sustains an injury there occurs at the time of the blow a sudden intense increase in intracranial tension, the range of which has been measured[186]. Mass movements of the brain also occur, a phenomenon which has been visually demonstrated. Injury may also produce an important molecular cell derangement representing a complicated physical-chemical cell change often of a profound degree and capable of destroying the function in vital medullary centers.

The mechanism of skull fracture has been now clarified[193]. It has been shown that when the skull is struck a blow, the area of impact is inbended while in bordering areas there is outbending. If the area of inbending following

impact rebounds without fracturing locally, a linear fracture may be initiated at a distance from the area of inbending due to tearing apart forces from the outbending. The linear fracture then extends both toward the point of impact and in the opposite direction. If the area of inbended skull fails due to the magnitude and velocity of the blow, a depressed fracture thus results. The type of depression and comminution of the fracture depends upon the velocity of the injuring object, to a less extent upon its size and shape.

High velocity wounds in warfare produced by shell fragments and bullets cause an important explosive force within the brain producing wide tract damage. Such an injury calls for a more extensive debridement than the low velocity but penetrating type of injury. These principles are discussed in the following pages under compound fractures of the skull.

### Diagnostic Considerations

Surgical treatment may be indicated in the management of head injury in approximately one-third of patients. The presence of lacerations, compound fractures, simple and compound depressed fractures, as well as intracranial bleeding, resulting in a mass lesion are indications.

Lacerations of the scalp should be carefully inspected for the presence of an underlying fracture If such a fracture line is clean, closure of the laceration in layers after debridement is a satisfactory procedure. In depressed and compound depressed fractures, the indication for surgical intervention is to minimize post-traumatic sequelae and to prevent intracranial infection. In both compound and simple depressions, the fragments of bone may have torn the dura and lacerated the brain. If there is a tear of the dura with underlying brain damage, post-traumatic epilepsy may result. Careful exploration of such cases, removal of necrosed brain tissue, careful closure of the dura, either primarily or with the use of a free graft, are indicated. After removal of the depressed pieces of bone, an extensive skull defect may result. This can be repaired by a tantalum cranioplasty at a later date. In the frontal sinus region an osteoperiosteal transplant from the patient's skull is preferable.

In patients who have intracranial extravasation, there are certain general diagnostic criteria which may indicate operative intervention These include changes in the conscious state, neurologic localizing signs, ocular findings, changes in vital functions, and spinal fluid abnormalities.

Changes in the conscious state are important. A normal state of consciousness is always a favorable sign and is a contraindication for operative intervention, except in cases of mechanical defects, such as simple and compound depressions Progressive return of consciousness is usually a contraindication for intervention. Progressive drowsiness, alternating periods of consciousness with periods of drowsiness, and disorientation may signify the

need for intervention if certain other signs are obtained. A lucid interval followed by drowsiness and unconsciousness is an important syndrome, but it does not always signify middle meningeal hemorrhage. It may also be seen with subdural hemorrhage, subdural accumulation of spinal fluid and edema of the brain. Progressive deterioration of the conscious state is an important sign suggesting the advisability of intervention. The patient who is already unconscious may show a deepening stupor by lessened responses to painful stimuli. The necessity for frequent examination in such patients is evident. Their reaction to stimuli as well as the presence of new neurological findings may determine the advisability of operative intervention.

Changes in vital functions, the pulse, respirations, temperature and blood pressure are important from both a prognostic and diagnostic standpoint. At times, the pulse rate may be alarmingly low. A low pulse rate is frequently associated with an enlarging clot, either extradural or subdural. A rate of 40 to 55 is occasionally seen with an otherwise normal patient. Such a patient is kept under close observation for other signs of increased intracranial pressure. Usually, the pulse rate rises to a normal level in from a few to ten days The presence of a low pulse rate is not an indication for operation, but a lowering rate is an important factor in establishing its advisability. In conjunction with other findings, such as increasing drowsiness, it becomes evidence favoring intervention.

The respiratory rate and the temperature are more frequently of prognostic significance. Increasing respiration soon after trauma indicates a poor prognosis. High temperature above 104° rectally soon after trauma also is of serious import. A lowering of the respiratory rate is seen in patients with increased intracranial pressure from mass lesions. Lowering respiratory rate, as well as a low pulse rate, frequently co-exist in many instances.

Blood pressure readings in some cases may be significant and may indicate an increasing intracranial pressure. Increasing systolic pressure in a patient who is becoming more drowsy may signify an expanding lesion.

Changes in pupillary size and ocular function are significant. The condition of the pupils, their size, their reaction to light and inequalities present are important both from a prognostic and a diagnostic view. A dilated pupil is practically always on the same side as an enlarging mass for which an operation may be contemplated. However, in a small number of cases, a dilated pupil may be found on the opposite side as seen in some patients with middle meningeal hemorrhage. Ocular paralysis, when present, usually means a mass lesion on the same side as the palsy. Dilated and fixed pupils spell a grave outcome; the same is to a less degree true in cases of constricted and fixed pupils. The presence of a pupillary inequality may be of help in lateralizing the lesions, but of itself, it is no indication for operative intervention.

The presence of edema or choking of the discs may indicate a mass lesion in the cranial cavity. In head injury, changes in the discs are not seen in the

early cases. On the other hand, repeated examinations may reveal a beginning edema or engorgement of vessels which may be suggestive of increasing intracranial pressure. It is interesting to note that in some patients who have been extremely ill, who appear to show evidences of improvement, the edema of the discs progresses. The significance of the late appearance of such edematous or choked discs is obscure. Possibly it may be related to dural sinus thrombosis.

Focal neurological findings when present serve two purposes. First, they serve in the localization of the pathologic lesion and second, their mode of development may serve as an indication for operative intervention. Hemiplegia, hemiparesis, Jacksonian convulsions, and sensory changes when detectable, usually denote pathologic changes in a definite portion of the nervous system. However, because of the presence of contrecoup lesions in head injury, neurologic findings of exact localization are at times quite misleading. Hemiparesis or hemiplegia on the same side as the cerebral clot is seen with sufficient frequency to warn the physician of this possibility. This may be explained on the basis of contrecoup involvement of the cortex on the opposite side by pressure from an enlarging clot, by a contrecoup lesion of the cortex at the time of accident as well as by uncal herniation and compression of the brain stem so that the opposite surface of the brain stem is under pressure by the tentorial edge of the dura.

The presence of a definite neurologic finding is not an indication for intervention. The mode of appearance of the neurologic finding is more significant Hemiplegia seen immediately following an accident has a different significance from a hemiplegia developing slowly and becoming complete within twelve to twenty-four hours. In the former, the hemiplegia is most probably indicative of contusion or laceration about the motor cortex. When hemiplegia develops slowly, the possibility of an enlarging clot as a causative factor is apparent. A combination of minor contusions of the motor centers and edema of the brain due to head injury may give the picture of a progressive paralysis; however, the spinal fluid in such a case is bloody, the pressure is not high and the patient usually shows improvement following a lumbar puncture.

Spinal fluid findings may be important. The blood content of the spinal fluid is of prognostic and diagnostic significance. A bloody spinal fluid does not exclude an extradural hemorrhage In most cases of middle meningeal hemorrhage in the authors' series, spinal puncture when performed yielded bloody fluid. When the spinal fluid is markedly bloody the possibility of associated brain damage should be kept in mind. Bloody spinal fluid does not rule out an acute, subacute or chronic subdural hematoma The spinal fluid pressure obtained by the water manometer is important. The pressure is frequently high in mass lesions, although not necessarily so in some patients with a subdural or an epidural hematoma.

In summary, a combination of signs and symptoms may indicate the need for surgical intervention. With constant attention to the patient's condition and the varying manifestations, one usually arrives at a sound conclusion as to the proper procedure. It should be emphasized that each case of head injury should be individually treated. There is sufficient variation in the manifestations of the pathological processes to make a routine policy dangerous.

Scalp wounds may be single or multiple, with healthy or extensively bruised and devitalized edges. *Penetrating wounds of the scalp with loss of tissue,* and avulsion of the scalp are other possibilities. In the accompanying page the management of a simple laceration of the scalp in the right frontoparietal area is shown in *1*. Such a laceration is treated by excision of the edges as shown at *b*, cleansing of the wound as shown at *c*, and debridement, if dirty and contaminated, as shown in *c*. Depending upon where the scalp wound is located, a three or a two-layer closure may be preferred. At *d*, *e*, and *f* a three-layer closure is shown, such as would be desirable in the frontal, temporal and occipital regions. The pericranium, with muscle tissue, may be the deep layer for suture; the second, the galea or subcutaneous fascia, *and the third, the scalp itself. Interrupted fine silk sutures are used.*

In *2* multiple scalp lacerations are shown. Such lacerations are carefully cleansed, the edges are debrided with care to conserve tissue and then the individual lacerations are sutured as shown at *b*. At times, these lacerations require caution to avoid tight approximation as a result of too liberal excision of the scalp edges.

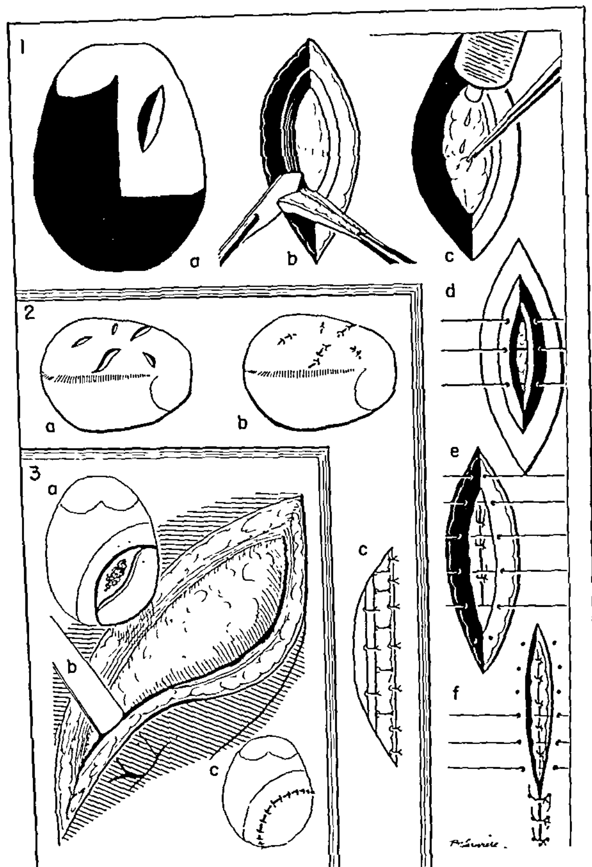
In *3* an extensively contused and lacerated area in the frontoparietal region near the midline is excised as shown at *a* and *b*. Through a curved incision the area is excised. Adequate closure is permitted when the scalp edges are carefully undermined, as shown at *b*. A two or three-layer closure *is used. The scalp then is closed with interrupted silk sutures as shown at c.*

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*Venous Drainage of the Scalp*

The venous drainage of the scalp is accomplished by the frontal and supra-orbital veins anteriorly, the temporal veins in the parietal regions and the occipital and posterior auricular veins in the posterior portions of the scalp. The frontal and supra-orbital veins unite at the medial *angle of the orbit to form the angular vein which continues down the* face as the anterior facial vein. The supra-orbital vein also communicates with the ophthalmic vein in the orbit, thus a communication exists between the anterior scalp veins and the ophthalmic vein which empties into the cavernous sinus. Infection of the face may thus extend into the cavernous sinus by retrograde thrombosis The superficial temporal veins follow closely the superficial temporal arteries and in the vicinity of the zygomatic arch they form the posterior facial which eventually empties into the external jugular vein. The superficial temporal veins anastomose with each other at the vertex and with the supra-orbital and frontal veins anteriorly. The posterior auricular vein empties into *the external jugular and it drains the portion of the scalp just posterior* and superior to the ear The occipital vein is positioned more medial to the posterior auricular and is in close proximity to the occipital artery.

*(Continued on page 176.)*




1 Single wound—a, b, c Edges excised and wound debrided. d, e, f. Three-layer closure
2 Multiple cuts cleansed and sutured, a and b
Lateral view of three layer closure, c
3 Single large area of contusion and laceration excised through curved incision and repaired.

In *1*, an example of extensive multiple lacerations of the scalp is shown. These are individually debrided and sutured in two layers.

In *2*, *3*, *4*, *5* and *6*, large areas of scalp loss due to high velocity wounds and wounding from other causes are shown[31a]. At *2* a superior parietal wound is excised by utilizing a parietal scalp flap. In *3* and *4*, a vertical parietal wound is repaired in two ways. As shown in *3*, double parietal scalp flaps are used and as shown in *4*, a fronto-parieto-temporal scalp flap may be used. A midfrontal, vertical wound is repaired by using a bifrontal scalp flap as in *5*, or by using an orbitofrontotemporal skin flap as in *6*.

It is important to cover skull and dura with scalp if at all possible to do so. When impossible, either a split thickness skin graft or a wet dressing may be used. The split thickness graft is applied to the pericranium which must be present to receive the graft. If bare bone is present, granulations must first be induced by multiple drilling into the diploe. If there is a loss of skull and dura, a temporary graft of fascia or pericranium may be used for covering the exposed brain. Ten days later this graft is removed and a split thickness graft applied. Later scalp closure may be accomplished at the time of cranioplasty. In certain cases it may be advantageous to slide scalp over a defect in the skull, leaving a portion of the skull and pericranium exposed, to be treated by skin graft immediately or at a later date.

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*Venous Drainage of the Scalp (Concluded)*

It may either empty into the vertebral or the deep cervical vein, or the internal jugular vein, or into the external jugular via the posterior auricular.

Extensive communications exist between the intracranial venous sinuses and the scalp through the emissary veins. The parietal emissary veins join the superior sagittal sinus with the temporal veins. The mastoid and the condyloid emissary veins join the scalp veins with the lateral sinus. There are venous communications between extracranial and intracranial structures through the diploe. The presence of the communications between the venous channels in the scalp and those of intracranial structures makes it possible for infection to enter the skull contents by retrograde thrombosis through such channels.

Scalp Wounds.

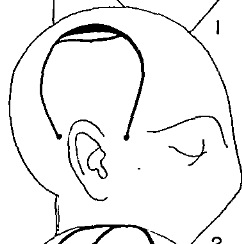
1. Multiple scalp wounds debrided and repaired with 2-layer closure.

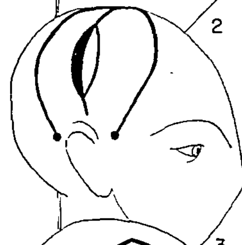
2. Large transverse parietal wound repaired with parietal skin flap.

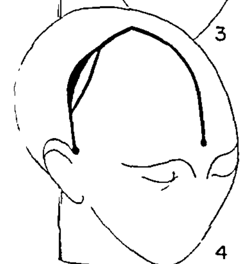
3, 4. Large vertical parietal wound repaired by double parietal skin flap 3, or by fronto-parieto-temporal skin flap 4.

5, 6. Vertical frontal wound repaired by bifrontal skin flap 5.
Or with orbito-fronto-temporal skin flap 6.









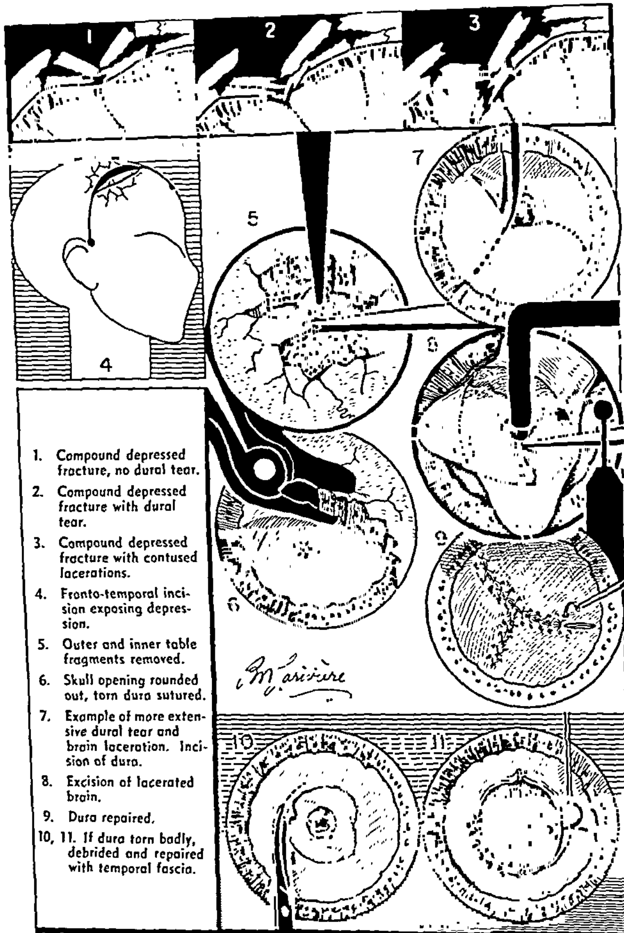
A frontoparietal depression is shown in *4*. In *1*, a depression with intact dura is shown. The outer table of the skull is extensively inbended. The inner table is also fractured but it should be noted that the inner table involvement extends beyond the outer table area of damage. In *2*, the depression is associated with an involvement of the dura. Again, the inner table involvement is much more extensive than that of the outer table. At times, such a pattern may necessitate removal of the outer to expose bleeding points of the inner table. In *3*, a more extensive depression, associated with a torn dura and lacerated brain by fragments of bone, is shown. Management of the various types of lesions is shown in *4* to *11*, illustrating cases with the dura intact, the dura torn, and the brain lacerated.

In *4*, the area of injury and the type of incision to expose the area as well as to excise the edges of the wound are shown. In *5*, the fragments of the outer and inner table are removed. In *6*, the dura has been exposed. There is a very small tear in the dura which has been repaired with one stitch The edges of the opening in the skull are rounded by rongeuring away a portion of the bone. In *7*, a lesion associated with laceration of the dura and involvement of the brain is shown. Where the laceration of the dura is limited a tripod incision may be used. The dura is then reflected as shown in *8*. The brain surface may then be dealt with. If there is an area of maceration, this is carefully removed with saline and gentle suction. Bleeding points are stopped by cautery or by the use of clips. The dura is then closed with interrupted silk as shown in *9*.

If the dura is found to be extensively damaged, necessitating debridement, as in *10*, the edges of the dura are cut with scissors and after dealing with the underlying brain, the area of dural defect is repaired by the use of a free graft of temporal fascia or pericranium, (*11*).

In the management of a depressed skull fracture, the site of depression is important. When the depression overlies the sagittal or the lateral sinus, the possibility of hemorrhage or air embolism exists Such possibilities should be recognized preoperatively.

Small tears in the sagittal sinus can be repaired by the use of gelfoam fixed in position with a stitch or two from the dura on one side of the sinus to the dura on the opposite side. A piece of muscle may be used in the same fashion. In the frontal area, midline depressions may be associated with a torn, lacerated sagittal sinus and in this situation, the sagittal sinus may be ligated for hemostasis. Tears in the posterior two-thirds of the sinus or posterior to the rolandic veins are best treated by maintaining the circulation if at all possible. In some instances, it may be possible to repair a tiny laceration in the sinus lining with silk sutures. In selected cases, one may repair the sinus by using a temporal fascia graft thus maintaining its patency The main venous flow and emptying veins at the site for graft may be temporarily plugged with gelfoam This tamponade is removed




1. Compound depressed fracture, no dural tear.
2. Compound depressed fracture with dural tear.
3. Compound depressed fracture with contused lacerations.
4. Fronto-temporal incision exposing depression.
5. Outer and inner table fragments removed.
6. Skull opening rounded out, torn dura sutured.
7. Example of more extensive dural tear and brain laceration. Incision of dura.
8. Excision of lacerated brain.
9. Dura repaired.
10, 11. If dura torn badly, debrided and repaired with temporal fascia.

when the last stitches have been placed about the graft. Local and systemic heparinization is indicated under such a circumstance.

The lateral sinus, when torn, may be dealt with by double ligation if necessary. The importance of adequate exposure before such a procedure is carried out is obvious.

## Cerebrospinal Fluid Rhinorrhea and Otorrhea. Pneumocephalus. Compound Depressed Fracture of the Frontal Sinus Neighborhood

### Historical

A thin, watery fluid was described by Prescott Hewitt in 1861 as issuing from the ear, nose or from other parts of the vault of the skull following cranial trauma, an observation which had also been made by older surgeons according to Hewitt. In 1839, Laugier perceived a watery discharge from the ear; upon postmortem dissection he noted the presence of a fracture of the petrous bone and a rupture of the tympanic membrane. At that time the origin of the discharging fluid was difficult to establish, but Laugier believed that the fluid may have been a serum from the extravasated blood clot lying in contact with the fracture of the bone. In similar cases other opinions held that this fluid was from the liquor cotunnii, the product of the membranous labyrinth (endolymph). The possibility of the fluid arising from the cavity of the arachnoid was also considered.

Hewitt stated that the discharge in some cases is due to escape of cerebrospinal fluid. He quoted Aberard and Nelaton who had the same opinion and Robert who noted the fluid to be of cerebrospinal fluid origin upon dissections in postmortem head injury cases. He also stated that Chatin found upon the analysis of the fluid that the composition of the discharge was similar to the cerebrospinal fluid in its very small quantity of albumin and a large quantity of sodium chloride.

Hewitt also reported upon watery discharge from the nostrils after cranial injury, but he thought that this was much more infrequent than discharge from the ear In 1840, Blandin at the Hôtel Dieu in Paris discussed this subject and in 1845, Robert encountered a similar case in which at autopsy the dura mater overlying the sella turcica was found torn, also, that the arachnoid membrane was also torn in the same region Moreover, watery discharge in the vicinity of the sella turcica was found to trickle down into the nose. In 1846, Malgaigne described a patient in whom there was a copious watery discharge from the ear and the nostril at the same time. It was considered to be a patient with cerebrospinal fluid rhinorrhea and otorrhea.

The management of compound depressed fractures about the frontal sinus neighborhood, cerebrospinal fluid rhinorrhea, and pneumocephalus has been discussed only recently Among others, Teachenor, Dandy[100], Peet[339], Rand[376], Coleman[51], Cairns[43], Adson[4], Gurdjian and Webster[155] have added to our present day knowledge of this subject It is generally accepted that

simple fractures in the region of the frontal sinus should be treated conservatively, except in cases with cerebrospinal fluid rhinorrhea, pneumocephalus, or both, in which operative intervention may be preferable. A laceration over a nondepressed fracture in this neighborhood is also treated by the most conservative method, namely cleansing and debriding of the wound and repair. Compound depressed fractures of the region of the frontal sinus are treated by operation after careful roentgen studies. Most authors extend the original laceration in order to get access to the area of damage. Some have suggested that a frontotemporal skin and bone flap is better for exposure and repair of the depressed fractures in the frontal sinus neighborhood.

Cerebrospinal fluid rhinorrhea may be spontaneous or traumatic. Instances of spontaneous type include cases with increased intracranial pressure due to tumor of the brain with thinning and eventual rupture of the neighborhood of the cribriform plate or erosion of the anterior fossa by the tumor. Internal hydrocephalus of childhood may be eventually associated with cerebrospinal fluid rhinorrhea by thinning and rupture of the neighborhood of the cribriform plate. Meningoceles of varying size in the region of the exit of the olfactory nerves may extend into the nasal cavity with external appearance of nasal polypi. Erosion of the roof of the nasal cavity by tumor or infection may eventuate in cerebrospinal fluid rhinorrhea. In a few instances of clinically proved cases of spontaneous cerebrospinal fluid rhinorrhea no cranionasal communications have been found. In these cases there may have been minute meningoceles about the exit of the olfactory nerves. Cases of traumatic cerebrospinal fluid rhinorrhea include those of discharge following a nasal operation or due to external injury to the head. Both the traumatic as well as the spontaneous type of cerebrospinal fluid rhinorrhea may last for many months or years, but the most frequent cause of death in both groups is the occurrence of meningitis. With the use of chemotherapy and biologic agents, this class of patient now comes into the hospital with a history of several attacks of meningitis. In our own group, we have had two patients, one with five attacks of meningitis and one with six attacks of meningitis, due to recurrent traumatic cerebrospinal fluid rhinorrhea.

The traumatic form of cerebrospinal fluid rhinorrhea may be seen during the acute stage of the injury to the head or as a late complication. The diagnosis of cerebrospinal fluid rhinorrhea is based upon the history of trauma, intermittent, and usually unilateral discharge of clear fluid, unassociated with upper respiratory infection and a chemical analysis of the fluid. The chemical analysis reveals sugar which is not present in nasal secretions. A simple method of recognition is the handkerchief test. The fabric of the handkerchief is not stiffened after drying when used, whereas watery nasal discharge causes a stiffening. In some instances, it may be possible to note the position of the cranionasal fistula by examination of the nose. If the fluid comes from the roof of the nose, a cranionasal fistula is probably through the cribriform plate. If it is below the middle turbinate the fistula is probably through the frontal sinus.

Management of cerebrospinal fluid rhinorrhea may be conservative or operative. In the absence of a compound depressed fracture in the vicinity of the frontal sinus or a comminuted fracture at the base of the skull near or at the cribriform plate, an acute case of cerebrospinal fluid rhinorrhea may be treated by bedrest. In the greatest majority of cases there is stoppage of the fluid discharge and cure of the condition is obtained. If cerebrospinal fluid rhinorrhea recurs on one or more occasions, closure of the fistulous tract without operative intervention is rare. In such cases, operative repair of the fistulous tract is indicated.

Patients with cerebrospinal fluid rhinorrhea associated with a compound depressed fracture of the frontal sinus region should be extremely carefully inspected for dural tears during the operation and such dural tears should be repaired meticulously.

Pneumocephalus is a common complication associated with cerebrospinal fluid rhinorrhea and fractures about the paranasal sinuses. It should be emphasized that pneumocephalus may exist without cerebrospinal fluid rhinorrhea and vice versa.

Air in the ventricular cavity was noted as early as 1884 by Chiari, and Luckett reported a case of traumatic pneumocephalus proven by x-ray examination in 1913. There has been a large accumulation of cases of this type since that time The reviews of Worms, Didiée, and Grumbach and Killian are interesting and important.

The presence of air in the cranial cavity of itself is no basis for concern except that following trauma it is due to the existence of a communication between the intracranial spaces and the outside air. Considered in this light it is a dangerous sign It may cause serious sequelae· first, by introduction of organisms into the cranial cavity and second, by increasing accumulation of air in the brain or the dural sac. Pneumocephalus may result in signs and symptoms of compression; including stupor, convulsions, paralyses, and speech disturbances

The entrance of air into the cranial cavity may be through a cranionasal fistula, through the ear, or a compound fracture of the convexity of the skull with dural tear and brain laceration. In the acute case, operative intervention may be indicated because of the presence of a compound depressed fracture. The otitic form usually can be treated conservatively, mainly by bedrest in semi-Fowler's position with good results. The repeating form of pneumocephalus deserves operative intervention by repair of the fistula which is usually a cranionasal communication

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*The Frontal Sinuses*

The frontal sinuses are two in number and are found immediately behind the superciliary arches of the frontal bone The two sides are rarely symmetrical There is a separating septum between the two In some instances there may be an intercommunication. Although their average size may be a little over an inch superoinferiorly and from side to side

and an inch deep, in some patients they are much more extensive. Roentgen examination to reveal the extent of the frontal sinuses when it is necessary to turn down a bone flap of the skull in the frontal region is important. The frontal sinuses communicate with the nose through the frontonasal duct which empties into the anterior portion of the middle meatus. The *frontal sinuses are fairly well developed* by the time the seventh or eighth year of life has been reached. They are absent at birth and are not a structure to be concerned about until at least three or four years after birth in the majority of cases. Their full size is reached after puberty.

### *The Sphenoid Sinuses*

There are two sphenoid sinuses, one on either side, and they are usually asymmetrical. They are contained within the body of the sphenoid bone. At times, they may be extremely large and thus extend into the basilar process of the occipital and into the pterygoid processes or the greater wings of the sphenoid bone. The sinus communicates with the sphenoethmoidal recess of the nose. The sphenoid sinuses are very small at birth and their development is completed after puberty.

### *The Ethmoid Sinuses*

The ethmoid sinuses are several thin-walled cavities found in the ethmoidal labyrinth and formed by the frontal, the lacrimal, the sphenoid, the palatine and the maxillary bones. They are found in the upper portion of the nasal cavity and between the orbits, being separated from these cavities by thin laminae. The lamina cribrosa, which covers their superior boundary, is *a very thin bony structure and may easily become* torn by trauma. In the presence of a dural tear, there may be cerebrospinal fluid leakage through the fistula. The ethmoid cells are divided into anterior, middle and posterior groups. The anterior and middle open into the middle meatus, the superior cells empty into the superior meatus. A few of the posterior ethmoid air cells may communicate with the sphenoid sinus. Although the ethmoid cells are not as well developed early in life, nevertheless, they are present during fetal life.

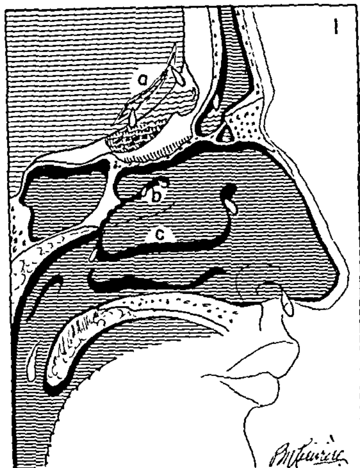
## Compound depressed fracture of the frontal sinus region. Cerebrospinal fluid rhinorrhea, otorrhea and pneumocephalus

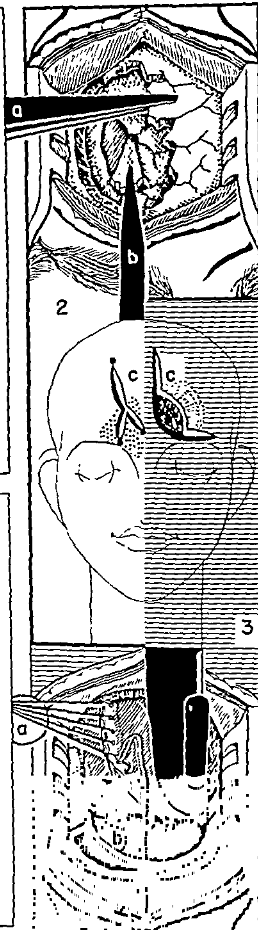
▶

In *1*, a diagrammatic representation of the path taken by cerebrospinal fluid in cases of traumatic cranionasal communication is shown. Laceration of the dura and arachnoid is shown at *a*. The fluid may escape through the cribriform plate and may be noted on nasal examination in the roof of the nose and superior turbinate bone *b*. The fluid may enter the frontal sinus and escape through the frontonasal duct below the middle turbinate bone *c*. The fluid may now escape via the anterior nares, In the supine position or in some patients who are up and about, the fluid may empty into the posterior nares and down the throat. Cerebrospinal fluid discharge may be elicited in the acute case by placing the patient's head between his knees while in a sitting position. Under these circumstances the fluid usually will escape from the nose.

In *2*, a compound depressed skull fracture of the frontal sinus region is shown. The original laceration may be extended as shown at *c* and the area of depression exposed. The outer wall fragments, as well as those of the inner wall, are removed The sinus mucous membrane is completely removed The dura is carefully inspected for tears If these are found they are repaired by interrupted silk sutures. Such a defect of the skull may result in a poor cosmetic appearance. Later repair of the skull defect with an osteoperiosteal transplant from the outer table of the skull is the procedure of choice. If at all possible, the orbital rim should be saved, since this makes a later repair much more manageable.

In *3*, a compound depressed fracture of the frontal sinus region with a dural tear is shown. The original area of laceration is excised with a curved incision as shown at *c* Then, the fragments of bone from the outer and inner table of the frontal sinus area are removed, exposing the dura with a tear which is being repaired as shown at *a*. We follow the tear in the dura as far posteriorly as it extends and close it by suture In many instances, the tear may be easily sutured. If on the exposure of the area one finds that there is extensive comminution of the crista galli and the cribriform plate region, then it is best to close the wound and later expose the anterior fossa by a more appropriate approach as shown on the next page




1a. Laceration of dura with cerebrospinal rhinorrhea.
b. Through crista to superior turbinate, to nose and throat.
c. Through frontal sinus into middle turbinate

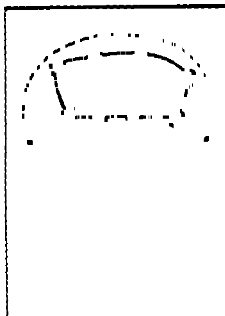
2. Depressed fracture of frontal sinus
a. Bone from outer table.
b Fragments from inner table.
c. Laceration over sinus extended superiorly.

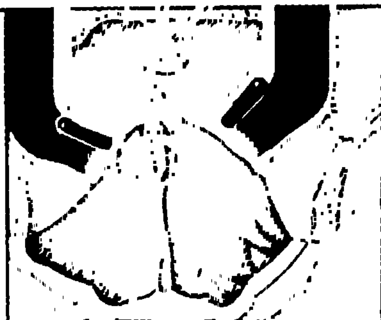
3 Compound depressed fracture of frontal sinus with dural tear.
a. Repairing torn dura after exposure.
b Cribriform plate.
c Area of laceration and excision of same.

Under these circumstances a bone flap may be turned, hinged to the right temporal muscle. A coronal incision to expose the frontal bone and a bone flap as shown in *1* is most adequate for bilateral inspection of the anterior fossa. The sagittal sinus is avoided by placing the openings in the skull on either side of the midline. In *2*, the anterior fossa is shown; at *a*, the dural tear and at *b*, the cribriform plate area are seen. The dura is carefully separated from the base of the skull and at the site of the laceration the dura is sutured. If it is found to be extensively lacerated with a large ragged defect, then this area may be repaired with a transplant of temporal fascia, easily obtained through the same exposure. The temporal fascia is as serviceable as fascia lata and is more readily available. After careful hemostasis, the wound is closed in layers

In the lower illustration there is an example of a chronic form of cerebrospinal fluid rhinorrhea. For the exposure of the cranionasal fistula, an adequate bone flap is turned, being hinged to the temporal muscle on the side of the fistula. A coronal incision is adequate and causes less visible scarring. The dura is separated from the bone in the vicinity of the cranionasal fistula. The adhesions are broken. It is important to extend the dissection of the dura off the bone about the cranionasal fistula to allow suture of the transplant to the border of the dural defect. When the dura is completely separated about the cranionasal fistula, the edges are freshened as shown in *3*. A piece of temporal fascia is passed under the dura as shown in *4*, and tucked in between the dura and the brain in such a manner that one can suture the fascia to the dura as shown in *5* By this technique the transplant is inside the dural sac. The possibility of necrosis is much less than if the graft were on the outside of the dural sac. It is important to test the closure for water tightness by injecting saline under the dura

In the acute, as well as the recurrent case of cerebrospinal fluid rhinorrhea, the area of tear may be inspected intradurally by opening the dura and elevating the frontal lobe. Particularly in the chronic form, there may be some evagination of the brain with adhesions at the cranionasal opening The brain should be separated carefully and the fistulous opening completely exposed. By extradural dissection the dura can be mobilized around the fistulous area Repair by fascial transplant with temporal fascia should be preferred over the placing of muscle or gelfoam in the fistulous tract





Below

1. Old cerebrospinal rhinorrhea, right side.
2. Position of bone flap.
3. Dural tear debrided
4. Temporal fascia tucked inside dural sac.
5. Watertight suture.

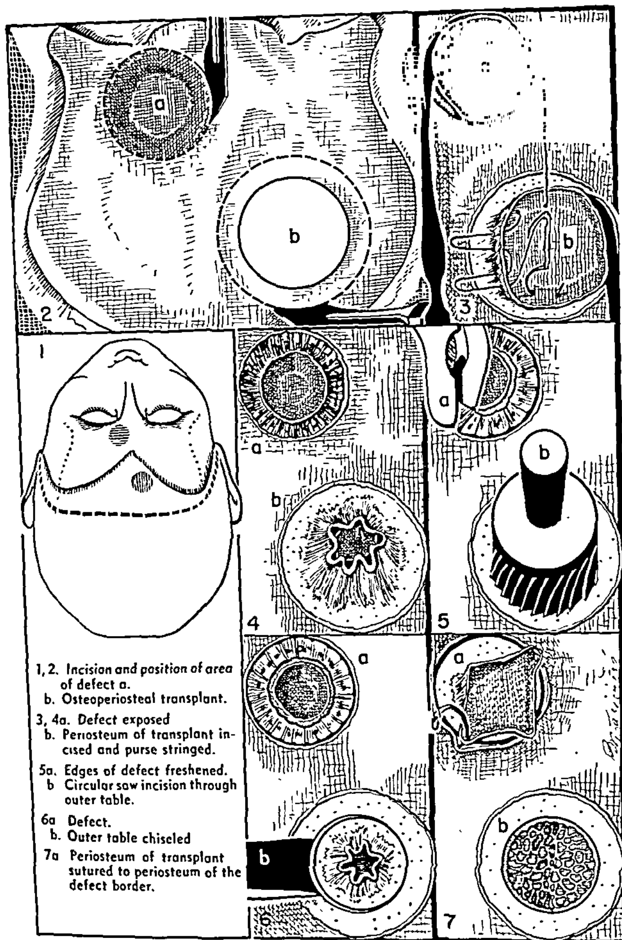
Above

1. Cerebrospinal rhinorrhea due to fracture of cribriform plate.
   a. Coronal scalp incision.
   b. Hairline.
   c. Bone flap hinged to right temporal muscle.
2. Exposure of cribriform plate and torn dura.
   a. Torn dura repaired.
   b. Comminuted fracture of cribriform.

*Historical Notes on Use of Skull Outer Table Grafts.* According to Reeves, Seydel, in 1889, repaired a left parietal defect with a graft from the tibia. In 1890, Mueller used the technique of swinging a flap of skin, pericranium and outer table of skull to repair a cranial defect. In the same year, Konig suggested the use of twin flaps, one containing skin and pericranium of the area of defect and the other, skin, pericranium and outer table of the skull in the adjacent portion. The latter was then transposed, sutured over the area of defect, while the former was transposed to the region from which the bony graft was obtained. Other names in the development of osteoperiosteal bone grafts include Durante, von Hacker, Keen[213], and many others. Outer table grafts from the skull are preferable to rib, tibia and ilium. Preserved bone also has been used for this purpose, and if it is found satisfactory the operative repair of some of these defects will become simpler.

Osteoperiosteal transplants are preferable to inanimate transplants in the repair of the smaller defects in the frontal sinus region. When the defect is rather extensive and also involves the orbital rim, larger transplants may be obtained from the outer table of the skull, but in many instances, transplants obtained with a circular saw are adequate for most defects. It has been shown that when tantalum cranioplasty is unsuccessful, this is frequently the result of contiguous frontal sinus infection. Defects in the frontal sinus area are therefore better treated by osteoperiosteal transplant if possible.

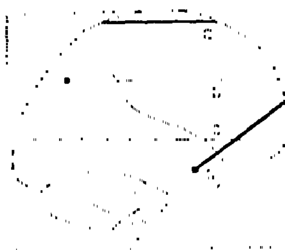
*Figure 1* shows the plan of a coronal incision, reflecting the scalp off the skull preserving the pericranium. The scalp is dissected off until the area of defect in the vicinity of the brow is well visualized. The pericranial lining at the edge of the defect is incised and with care is reflected until the edge of the bone is exposed about the defect. At this point a template may be used of paper or rubber dam to outline the size of the defect. By placing the template on the skull in the frontoparietal area as shown in *2b* an area of bone to be removed is outlined. The pericranium of this area is then cut beyond the portion which is to be sawed with a circular saw as shown in *2*, at *b*. In *3*, the pericranial edge of the defect is being reflected as shown at *a* As shown at *b*, the pericranium of the area of bone to be transplanted is incised circularly and puckered toward the center with a purse string suture as shown at *4b*. The edge of the defect is freshened as illustrated in *4a* and *5a*. A circular trephine is used to cut into the outer table of the skull to the diploe as shown in *5b*. A sharp chisel may now be used to cut through the outer table of the skull as shown in *6b*. The chiseling is done from several directions, care being taken to avoid cutting into the inner table After freeing the graft, there may be bleeding from the diploe which is controlled with bone wax. The pericranium of the transplant is sutured to the pericranium about the area of the defect, *7a*, after the bony portion of the transplant is fitted, if necessary, by removing excess bone with a rongeur After stopping all bleeding points, the scalp is now closed in two layers with silk.

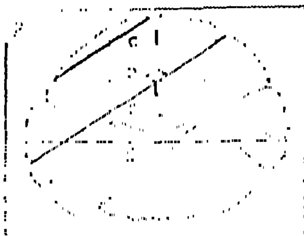

a
b
2
b
3
1
a
a
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b
4
5
a
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b
7
1, 2. Incision and position of area of defect a.
b. Osteoperiosteal transplant.
3, 4a. Defect exposed
b. Periosteum of transplant incised and purse stringed.
5a. Edges of defect freshened.
b Circular saw incision through outer table.
6a Defect.
b. Outer table chiseled
7a Periosteum of transplant sutured to periosteum of the defect border.

Bullet wounds of the head may commonly involve the craniocerebral structures in directions as shown in *1* and *2*. In *1*, at *a*, is shown a tangential missile course which usually undermines the scalp, fragments the bone, and tears the dura extensively, at times guttering the cerebral surface. The patient usually survives. At *b* is shown an anteroposterior penetrating wound track with the missile still in the posterior portion of the hemisphere. At *c* is shown an anteroposterior perforating wound track with a missile having exited posteriorly. The types seen in *b* and *c* have a high mortality.

In *d*, is shown the course frequently seen in suicide cases where a bullet enters the temporal area and exits in the forehead region on the same or opposite side. Many such cases survive the initial injury but may succumb to a complicating cerebrospinal fluid rhinorrhea with infection. In *2*, in a *coronal section of the brain is shown a tangential* course at *a*, a *perforating* wound at *b*, high enough for the possibility of survival, and a perforating transventricular course at *d*, which is almost always fatal. At *c* is shown a perforating wound in an oblique direction, with the wound of entrance in the parietotemporal area on the one side and the exit in the superior parietal area on the opposite side. At *e* is shown the usual suicidal bullet path when the gun is held against the roof of the mouth.

In *3*, *4*, *5*, and *6*, are shown the theoretical extent of damage of the cerebral tissues in the missile's path, and the area requiring thorough debridement. In *3*, *4* and *5* the missile is in the brain. There may be many fragments of bone indriven in the path of the shell fragment or bullet The path of the missile is conical in shape and is made up of pulped brain tissue. This area should be completely debrided by suction with removal of the foreign matter, including fragments of bone, hair, organic particles and the missile if possible. In *5* and *6* are perforating wounds of the brain Almost always such *wounds are fatal. In 5 the bullet has traversed the head anteroposteriorly* and has lodged immediately inside the skull posteriorly. Under these circumstances the area of entrance is carefully debrided, including the scalp, skull, dura and brain The path of the bullet is carefully cleansed by suction and *irrigation with saline*. Fragments of bone *preoperatively identified in the* x-ray films are sought for and removed As shown in *5* and *6*, when the missile has perforated the brain both the wound of entrance and the wound of exit must be debrided This often requires two steps with redraping of the separate areas of exposure. Emphasis should be made that *the compound* fracture produced by a high velocity penetrating missile requires a more radical debridement of the cerebral tissue than the pulped area of damage resulting from a civilian wound by lower velocity objects





1a. Tangential wound.
b. Penetrating anteroposterior wound.
c. Perforating anteroposterior wound.
d. Temporofrontal wound.

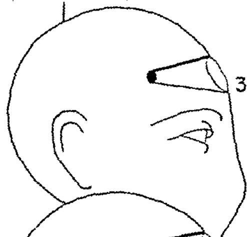
2a. Tangential wound.
b. High transverse wound.
d. Low transverse wound.
c. Oblique temporoparietal wound.
e. Baso-vertex wound.

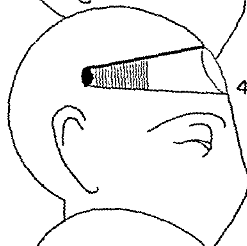
3. Area of frontal bullet wound requiring debridement.

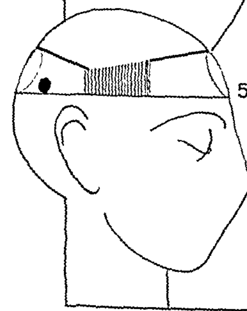
4. *A more extensive anteroposterior wound* and area of destruction requiring debridement.

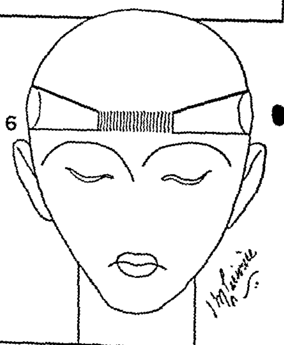
5 Perforating anteroposterior wound.

6. Perforating transverse wound.



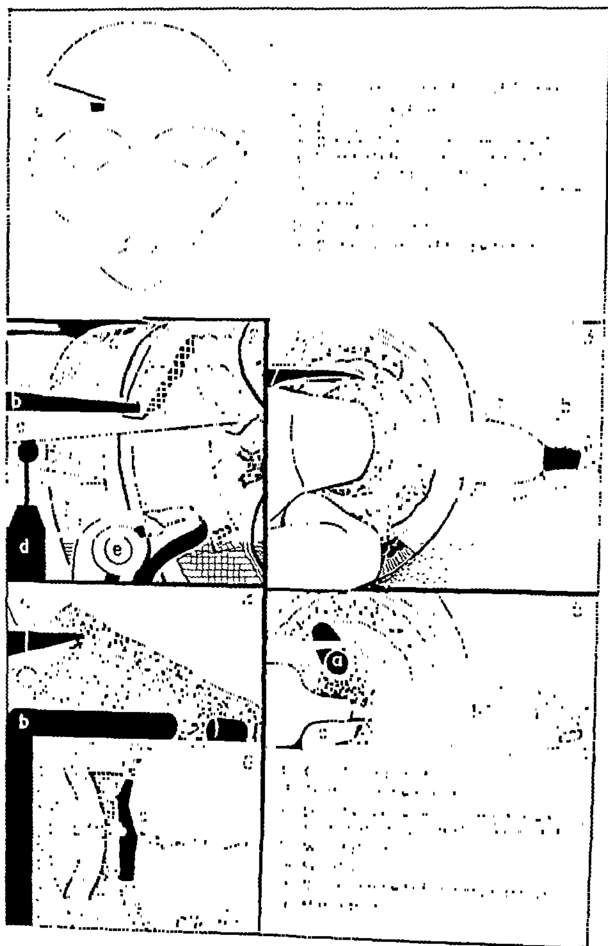





In *1* is a diagrammatic example of a bullet wound in the temporoparietal area with the missile in the brain. Excision of the wound of entrance is shown *on page 174. In 2, at a, the area of perforation of the skull is exposed;* the comminuted fragments of bone are carefully removed. The underlying dura is completely exposed. It may be necessary to make a burr opening adjacent to the perforated area. The bone is then rongeured away, exposing the point of dural penetration. In other cases, the dura may be easily separated from bone fragments with a dural elevator. The opening in the skull may be made oval or round, depending upon the site of the wound. Consideration must be given to future cranioplasty at this time. The dural tear is now carefully debrided as shown in *3*, at *a*. The various fragments of bone that are indriven in the vicinity of the area of entrance are removed. Preoperative roentgen studies show the number, size and position of such fragments. To note the presence of fragments of bone, the index finger may be introduced into the brain in the path of the missile. Even small fragments of bone may be palpated by this method as the finger is permitted to pass along the path of the bullet The metallic fragment or fragments may also be felt by this means. The area of the brain destruction is now carefully debrided by suction. Contused and damaged brain is sucked out with care with a pressure *machine of 15 pounds per inch. The various bleeding vessels caught with* the suction are controlled by the cautery or with clips. Fragments of bone are removed, always keeping in mind that the preoperative roentgen studies are a good guide as to the presence and number of fragments to be removed. If the shell fragment or bullet is accessible, such as would be in this instance, it can be removed. It is quite likely that a sizeable dural defect necessitating a graft will be present. An excellent material for a dural graft is temporal fascia or the pericranium As shown in *b*, in *6*, such a graft has been used to repair the dura The path of the bullet usually collapses as shown at *c*. No organic foreign material should be left in the path of the missile, including gelfoam,* cellulose cotton, etc , unless unavoidable. The skin is closed in layers and without drainage.

The management of wounds caused by shell fragments follows essentially the same plan employed in the case of a bullet wound, excepting that one has to be more cautious in removing all fragments of the shrapnel Shell fragments are ragged and often carry organic material on their surfaces resulting in later infection After assessing the position of the shell fragment or fragments, in the preoperative roentgen studies, removal is usually possible Where there is an extensive dural tear, this is repaired with temporal fascia or pericranium When the scalp is badly destroyed over the area of wounding, a sliding graft of the scalp may be used to cover the area of defect in the skull and over the defect in the dura In other instances, it may be possible to cover the scalp defect by a method such as shown on pages 174–177.


b
d
e
b
a

## Management of Penetrating Wounds of the Brain—Certain Conclusions

Management of penetrating wounds of the brain by high velocity missiles was well worked out at the conclusion of World War I. The papers of Cushing[31] laid the foundation and theoretical grounds for the management of this class of patient. During World War II, with the help of better trained personnel and the necessary instruments for operative intervention, the practical demonstration of what could be accomplished was given. A thorough debridement, removal of all foreign and organic matter and removal of all clots and destroyed brain tissue was accomplished in many instances with no sequelae of infection. The suggestions of Horrax[223, 224], who advocated wide excision and thorough tract cleansing, were followed with excellent results. That chemotherapeutic and biologic agents undoubtedly were of inestimable value in conjunction with good surgical management, is unquestioned.

If a patient with a bullet wound is in a moribund state on entrance to the hospital, resuscitative and supportive treatment is indicated. Probably little can be accomplished, for he will die within a few hours of the injury. Among those who seem to improve, operative management for removal of blood clots from the bullet tract with careful debridement may be life saving. The prevention of late sequelae in the form of meningitis or brain abscess depends upon a careful and complete debridement of the brain and cranial structures The skull defect may be exposed by long curved incisions; bone should be rongeured away rather than removed en masse and the dural defect should be exposed. The dura should be debrided followed by debridement of the brain and the tract. Suction is of inestimable value in this connection. Electrocautery is used for hemostasis. Gelfoam,® cellulose cotton with thrombin may be indicated in some cases. In the presence of dural defects, repair with temporal fascia is satisfactory. Blood transfusions during operation are very helpful.

Metallic foreign bodies in the cranial cavity should be removed whenever possible There is no reason for leaving them in the cranial cavity if they are easily accessible. Foreign bodies which have lodged in the cranial cavity for many months or years, such as broken knife blades or ice picks, should be removed An inaccessible bullet which remains asymptomatic for many months or years may eventually cause symptoms necessitating operative removal

Early debridement whenever possible should be carried out, but a delayed primary debridement of wounds twenty-four hours to ten days is also possible and if done carefully the wound may heal by primary intention and without drainage.

The formation of a brain abscess in penetrating wounds of the brain is almost always due to retained bone fragments, organic matter and pulped and infected brain tissue There is a marked difference between civilian and military forms of brain abscess A so-called simple drainage of a brain

abscess following a gunshot wound is seldom successful. Excision of the abscess, fragments of bone, hair and other foreign matter is mandatory if a good result is expected in cases of this type. On the other hand, the so-called civilian abscess can be drained with success and can be treated by repeated aspiration and penicillin instillation as discussed under brain abscess management.

In extensive cranio-orbital wounds in military practice management depends somewhat upon the extent of the damage. Extensive dural tears and cerebral tissue damage and involvement of the paranasal sinuses may be present. Dural defects should be closed with a temporary graft of fascia lata. After two weeks the graft is removed and a split thickness graft is applied to the granulating area. In the debridement of the sinuses it is important to remove all devitalized tissue, bone fragments and the sinus mucous membrane. In patients who have had penetration of the frontal area, the orbital roof and the base of the frontal lobe, by small metallic fragments, a bone flap may be turned to advantage. Such an exposure allows excellent debridement of the bony and brain injury as well as repair of the dura either by suture or graft. Extensive skull defects in the frontal area, due to bone loss, may thus be avoided.

## Epidural Hematoma

### Historical

The possibility of hemorrhage immediately under the bones of the skull following trauma to the head, has been considered an operable condition for several centuries. In 1739, Heister stated that, "if the quantity of the extravasated blood be ever so small it will certainly corrupt and affect the meninges and brain itself". Two general policies of management developed in dealing with intracranial compression from hemorrhage. One group, which included the members of the French Academy of Surgery, who during the eighteenth century dominated surgical teaching, along with Percival Pott[359] in England, believed in a radical use of the trephine as a measure to avoid the suppurative or inflammatory effects of compression. It was a common practice for surgeons of this group to make numerous perforations along the whole tract of a fracture of the cranium Mr. Pott also advised such an operation with a view to prevent the possible inflammation or suppuration of the dura which he was so worried about Opposed to such radical practices were a conservative group of authorities including Desault of France, Richter of Germany, and Dease and O'Halloran of Ireland, who felt that the unnecessary use of the trephine was to be condemned. Abernethy, in 1811, recognized the importance of employing the trephine for extravasations of blood. Describing an extradural type of collection he

stated, "If a fracture of the skull happens in the tract of the principal artery of the dura mater, if the trunk or even a considerable branch of that vessel be torn, the hemorrhage will be profuse, and the operation of the trephine immediately becomes necessary to preserve the life of the patient". He reviewed three such fatal cases and stated that, "it could scarcely be doubted that if the operation had been performed in these cases as soon as it became necessary, when perhaps only one instead of many ounces of blood were poured from the torn vessel, the lives of the patients might have been preserved". He felt that the distinction between patients with an extravasation of blood in the epidural area from other types of intracranial trauma was made by the presence of an interval of conscious state between the blow and the stupor. Such a symptom complex was in favor of a mass hemorrhage, according to Abernethy. An interval of conscious state following a blow before unconsciousness supervened was considered of prime importance by Prescott Hewitt[210], but he stated that associated injury often could obscure the diagnosis and quoted the records from St. George Hospital of twenty-five patients with large extravasations of blood between the bone and the dura mater in all of whom the brain was more or less extensively lacerated. Hewitt stated, "This easily explains the difficulties as to diagnosis and the reason why the trephine is so seldom applied nowadays for extravasated blood and why, also, when resorted to, the operation so seldom succeeds". In the earlier part of the nineteenth century, a general conservatism was the rule and Hewitt's viewpoint reflected the teachings of the conservative school. This group thought Pott's[359] concept of making trephine openings into the cranial cavity was a false doctrine. The followers of the conservative viewpoint found solace in arguments as pointed out by Stromeyer[417], who reported, "during the three years he attended the hospitals of Vienna, London and Paris, he had not met with a single successful case of any serious injuries which recovered after trephining". The Glasgow Hospital registry showed no case record of recovery after trephine, and in the Paris hospitals, Nelaton found that in fifteen years all the operations of this kind for traumatic effusions had ended fatally.

Hutchinson, in the early part of the nineteenth century, noted that an extradural clot extends toward the base. In this way, he thought that it might exert pressure on the cavernous sinus, leading to fullness of the vessels with protrusion of one eyeball and dilatation of the pupil Hemiplegia on the opposite side of the body would also ensue Charles Bell[22], in 1860, discussed the mechanism of meningeal hemorrhage. He suggested that the blow upon the cranium first separated the dura from the bone. This separation then was continued by meningeal bleeding which followed the disruption of the vessels. Erichsen[139] believed that trephining was possible only in the meningeal forms of extravasation, although the effectiveness of this treatment was not convincing

Diagnostic features of extradural hemorrhage became the subject of extensive study by Hutchinson, Jacobson, Krönlein[271], Wiesmann, Gross[181] and many others in the latter part of the nineteenth century The anatomy of

the middle meningeal vessels was discussed by Plummer and this work is still the ranking classical description of these vessels. In the early history of extradural hemorrhage, a case of bilateral middle meningeal hematoma treated by Hill stands out, reported in 1750. Guthrie[93], in the early part of the nineteenth century, discussed the possibility of middle meningeal hemorrhage from perforating wounds of the head and gave examples. Since 1900 the management of epidural hematoma has received considerable attention. Different types of lesions have been described, including hematomas arising from rupture of the sinuses, particularly the lateral sinuses, the latter resulting in a posterior fossa hematoma, with certain characteristic signs suggesting posterior fossa involvement, mainly weakness and atonia of the half of the body on the same side as the hematoma compressing the cerebellum. Cushing[76], Krönlein[273], Keen[253], Krause[267] and others suggested operative procedures for the management of this type of lesion. A subtemporal decompression of Cushing was widely used for this purpose. Krause suggested the use of an osteoplastic flap. Present day management of this condition is by a subtemporal decompression or an osteoplastic craniotomy opening.

The epidural hematoma may be of middle meningeal arterial origin or it may result from a tear of the sagittal or lateral sinuses. The most common form of epidural clot is that of middle meningeal origin. Epidural clots caused by diploic bleeding are not usually of sufficient size to cause symptoms.

Among the diagnostic aspects of an epidural hematoma is the important finding of a dilated pupil on the side of the lesion. When the pupil is dilated the possibility that the lesion is more toward the base of the skull has to be kept in mind. In many instances, where the pupils are equal or the inequality is minor, the epidural hematoma has been found over the convexity of the hemisphere and away from the middle fossa at the base In a certain number of the cases, there may be a lucid interval and this may last anywhere from four or five hours to as long as a month. The frequent finding of contralateral weakness or paralysis must be looked for. A dilated pupil on the one side with a weakness or paralysis of the opposite half of the body in a patient who is becoming more unconscious by the hour suggests the occurrence of an extradural hematoma. Angiography has been of value in the proper localization of an epidural hematoma.

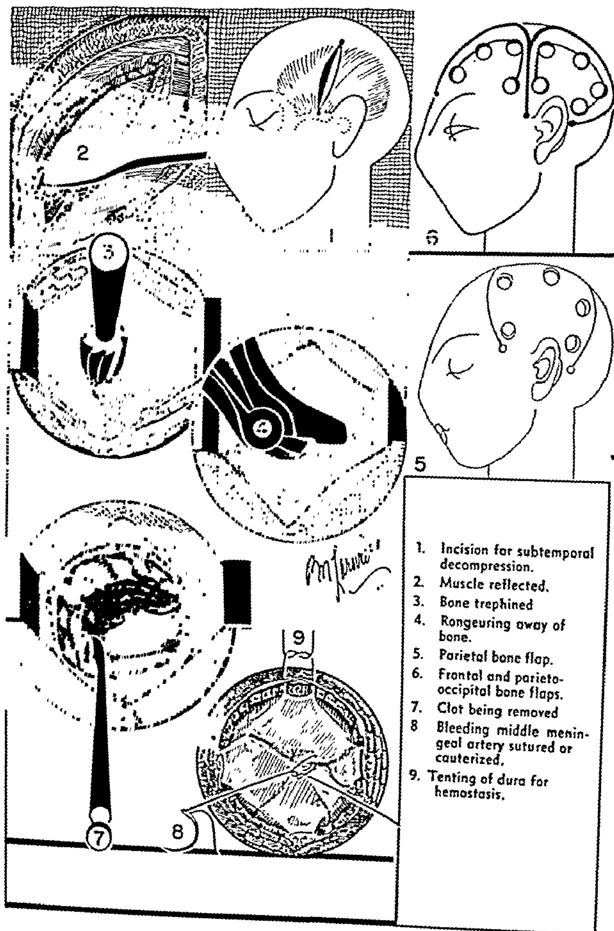
In the management of an epidural clot, a subtemporal decompression may be used for evacuating the clot. If a fracture has already been shown in roentgen studies, a trephine opening in the temporal bone in the vicinity of the fracture, may reveal the presence of the collection. Under these circumstances a subtemporal decompression may be adequate to remove the clot In other instances, a hematoma may be found more forward toward the frontal area or more posteriorly toward the parietooccipital region. Under these circumstances a bone flap of adequate proportion is the operation of choice Following the removal of the clot the bone flap may be replaced without a bone defect—the disadvantage of the subtemporal decompression

## Management of epidural clot by subtemporal decompression or adequate bone flap ▶

In *1*, the incision for subtemporal decompression is shown. In *2*, the temporal fascia and muscle have been incised and the bone is being exposed. In *3*, the temporal bone has been exposed by retraction and an initial opening is being made with the Hudson drill. In *4* the initial opening is enlarged to the size of a silver dollar or larger. The clot can now be seen immediately under the bone and between it and the dura. This clot may be removed by suction or with a brain spoon. This is shown in *7*. Following the removal of the clot it may be found that the dura is relaxed and depressed. The bleeding points resulting in the large hematoma may be noted and either tied as shown in *8*, or coagulated with the electrical unit. Usually, it is also necessary to tent the dura. Following the removal of the clot and hemostasis, the incision is closed in layers, usually without drainage, although a drain may be used if desired. The drain may be removed at the end of eighteen hours.

In other instances, if an epidural clot is found in the frontal or the parieto-occipital area, the patient may be treated by an adequate bone flap as shown in *6* and *5*. In our experience, about half of the patients with epidural hematoma are treated by small bone flaps, the other half are treated by subtemporal decompression.

Epidural hematoma of lateral sinus origin should be sought for in patients with occipital fractures. No definite localizing signs may be elicited, although typically cerebellar hypotonia with paralysis of one or the other half of the body may be obtained. The spinal fluid may be bloody or clear. *Increasing stupor with or without definite localizing findings should suggest the possibility of a posterior fossa epidural hematoma in the presence of an occipital bone fracture.*




1. Incision for subtemporal decompression.
2. Muscle reflected.
3. Bone trephined
4. Rongeuring away of bone.
5. Parietal bone flap.
6. Frontal and parieto-occipital bone flaps.
7. Clot being removed
8. Bleeding middle meningeal artery sutured or cauterized.
9. Tenting of dura for hemostasis.

## Historical

Discussions on extravasation of blood beneath the dural lining prior to the latter part of the nineteenth century are characterized by a feeling of hopelessness since neither could the clot be removed nor could a good outcome be obtained. Poor results were caused by infection of the meninges or in other instances, hernia of the brain tissue. Abernethy, in 1811, pointed out that "in those cases which I have seen, where blood was extravasated between the dura mater and the pia mater, and a division of the former membrane was made for its discharge, in some instances the serous part of it only could be evacuated, for the coagulum would spread over the hemisphere of the brain and had descended as low as possible towards this inferior part. In others, the lower portion of the diffused blood was discharged in a fluid or grumous state, a considerable quantity which was coagulated remained behind, so that very little relief was obtained by the operation". Abernethy concluded that the only type of intracranial hemorrhage that could be helped by the trephine was the extradural collection In 1851, Prescott Hewitt[210] pointed out that traumatic extravasations of blood occur "in the cavity of the arachnoid" and that the extravasated blood undergoes various changes in the course of time. He described the collection as becoming coagulated, flattened and molded. He noted the presence of a membrane of different hues, and stated that "the false membrane is firmly attached to the parietal arachnoid, its free surface perfectly smooth and polished and presents the appearance of a serous tissue, and its structures throughout plentifully supplied with blood vessels, which may be readily seen with the naked eye". It was pointed out that if the extravasation is a large one, it may in the course of time give rise to the formation of a large, perfectly closed bag, in which are contained the more fluid parts. The observation was also made that the pressure of the cyst in long-standing cases diminished the thickness of the bone, and in some cases, when formed in early childhood, such cysts had been known to lead to bulging of the bone outward.

Subdural extravasations made a greater claim upon the attention of the pathologists than the surgeons during the seventeenth, eighteenth and early part of the nineteenth century. Wepfer, in 1657, Morgagni, in 1747, both identified subdural hematoma as a cyst of blood beneath the dura. Houssard in 1817, Bayle in 1826, and Cruvielhier and Heschl suggested an inflammatory origin for the subdural collection of blood. In 1857, Virchow[427] submitted his studies on the subject which have subsequently served as a landmark. Virchow reported that the basis for this lesion was an inflammation of the dura which frequently occurred among the insane The inflammation of the dural layer resulted in the formation of an underlying membrane due to the deposition of fibrin which became organized This layer was highly vascular and thus productive of hemorrhages, either minute or massive He used the term, pachymeningitis interna chronica to identify the formation

of the membrane, while if hemorrhage occurred, this was termed a pachymeningitis hemorrhagica. The term hematoma of the dura was also used to define the collections of blood associated with the subdural membrane. It is also of note that Virchow recognized that a cyst of the dura might contain serum which was referred to as a "hygroma" of the dura. The studies of Kremiansky in 1868 emphasized that a generalized disease process was responsible for this subdural lesion. A history of chronic alcoholism commonly occurred among the patients affected with this disease. Experiments upon dogs administered brandy over a period of several months resulted in duplicating the lesion in the majority of the experiments, according to this author. Sperling in 1872, and Ford Robertson discussed this problem. The latter studied the formation of the subdural membrane in detail and related its formation to the possibility of a traumatic effusion. He suggested that the hemorrhage occurred from the rupture of a pial vein into the subdural space.

In general, however, the chronic form of subdural hematoma was viewed as a medical disease unrelated to trauma. Because of the obscure etiology, the pathophysiology of the lesion remained confusing to those who viewed the lesion at autopsy. Its infrequency in this period can probably be related to the fact that the acute subdural hematomas were usually associated with death. Many of the chronic collections were among the patients who reached institutions and upon whom autopsies were not performed. The correct position of the hematoma between the dura and the arachnoid membrane was first identified by Virchow.

Surgeons found that subdural extravasation was not only difficult to treat but also difficult to diagnose. Hewitt, for instance, stated that "there were no symptoms which enabled a clear diagnosis of an extravasation of blood in the cavity of the arachnoid". The presence of masking, due to associated brain damage, was also emphasized. Gross[131] noted that a subdural extravasation may occur from a trifling cause. Erichsen[139] noted that subdural extravasations were far more common than epidural hemorrhages. Progressive coma, the presence of a hemiplegia, stertorous breathing and a dilated and insensitive pupil were present in cases of subdural hematoma. The possibility of subdural effusion in infants was considered and discussed by Gross. Unconsciousness, convulsions, and spasmodic twitchings were some of the symptoms noted in infants afflicted with this condition. The fontanel was found to be tense according to Gross in this condition.

In the early part of the twentieth century, Cushing[76] believed that a subdural hemorrhage could be evacuated with results comparable to that of the extradural type. He recommended the use of a subtemporal decompression. After opening the skull, the dura was opened and the temporal lobe was elevated and as much of the bloody fluid was removed as possible. A rubber drain was used to permit further drainage after closure of the wound.

More precise pathophysiological concepts developed during the early part of the twentieth century. An important report was made by Bowen in 1905. Trotter in 1914 reviewed several cases of chronic subdural hematoma and established a relationship to trauma. In 1925, Putnam and Cushing

reported on chronic subdural hematoma and discussed its pathology, its relationship to pachymeningitis hemorrhagica and its surgical treatment. Dandy[105] in 1929 reported upon the excellent results obtained by drainage of these lesions. In 1932, Gardner gave an explanation for the expanding quality of the lesion as well as the dynamic clinical syndrome caused by subdural hematoma. He suggested an osmotic mechanism as a basis for the increasing size of the hematoma with migration of tissue fluids and cerebrospinal fluid into the subdural space where a high osmotic pressure was exerted by the presence of the clot. In 1934, Munro[318] reported upon studies reviewing the life cycle of subdural hematoma and also made suggestions for treatment. Kennedy and Wortis called attention to the acute type of subdural hematoma, its diagnosis and treatment. Browder, Coleman[70], Bucy[35], *Echlin, Fleming and Jones, Voris[439], and many others have recorded their* experiences with this lesion.

On the basis of our knowledge accumulated up to the present time, subdural hematoma is almost always traumatic and whether it is an acute, subacute or chronic lesion depends upon its size at the time of the initial hemorrhage. If the initial hemorrhage following trauma is sufficiently large, immediate symptoms and signs may result. On the other hand, the patient with a subdural hemorrhage can compensate for the presence of this lesion and he may carry on for several days or even several weeks without many symptoms If the lesion causes symptoms within a week to fifteen days, the lesion empirically may be termed subacute. Whereas, a collection which permits the patient to carry on practically symptom free for three or more weeks is considered a chronic form of subdural hematoma. A small bloody collection in the subdural space resulting from tear of veins extending from the surface of the brain to the dura, or entering the sagittal sinus from the surface of the brain, produces increased osmotic pressure in the subdural space. Tissue fluids and cerebrospinal fluid migrate into the subdural space through the semipermeable arachnoid membrane. Thus the mass in the subdural area slowly progresses in size until symptoms and signs supervene. At the same time, on the dural side, there occur evidences of tissue proliferation, resulting in the formation of a membrane surrounding the blood clot The membrane on the dural side becomes quite thick, containing many blood vessels which may bleed into the subdural mass. At the borders of the *clot, cuboidal epithelial growth occurs, covering the deeper surface of* the clot in juxtaposition to the arachnoid membrane. Thus, a chronic form of the subdural hematoma enclosed in a thick lining under the dura and a very thin epithelial lining over the arachnoid with central semiliquid and clotted material is formed Such a subdural hematoma is most often over the frontal and parietotemporal regions of the brain

## Present Day Surgical Management

Present day surgical treatment of subdural hematoma includes a variety of methods of management Burr openings were early used for diagnostic purposes Once identified the lesion was then treated by the customary use

of an osteoplastic craniotomy. In 1932, Fleming and Jones reported upon the fact that it was possible to treat the chronic form of subdural hematoma by drainage through diagnostic burr openings. This has been confirmed by many others. *The same plan of burr openings and* evacuation by this method has been applied to the more acute varieties of this lesion. Other methods have included enlarging the initial burr opening after the diagnosis has been made to allow sufficient room for evacuation of a solid or partially clotted hematoma. The use of the subtemporal decompression routinely, regardless of the boundary of the hematoma and finally the use of an osteoplastic flap constructed about the diagnostic openings are also procedures utilized in management.

By means of angiography, it is possible to establish the diagnosis and localize the extravasation prior to surgical treatment. Surgical treatment can then employ the most suitable method for evacuation of the lesion. A preliminary burr opening can be made to establish the fluidity of the collection. If the clot is fluid, a counter opening may then be used to complete the evacuation. If the collection is established as being solid and unsuitable for evacuation through simple burr openings, then the most suitable means of opening the skull at the site of the lesion should be employed. This has proved to be an osteoplastic craniotomy. This operation has the advantage of avoiding the production of a permanent bone defect. At the present time it is also a much less formidable operation than it was at earlier periods.

The earlier a subdural hematoma causes signs of compression, the more serious is the prognosis. The subdural hematoma which causes compression in less than twelve hours is usually fatal whether it is removed or not. After twenty-four hours to a week, a subdural hematoma may be treated with greater success The signs and symptoms of a subdural hematoma include pupillary inequality which is not as frequently seen as in extradural hematoma, and a weakness or paralysis in one half of the body with confirmatory pyramidal tract signs. Associated with these findings may be a deteriorating conscious level and increasing coma in an already stuporous patient. It is to be noted that the spinal fluid in many of these patients is bloody The spinal fluid pressure may not be high. A bloody spinal fluid with a low spinal fluid pressure does not exclude a hematoma *of operable* proportions. The presence of a skull fracture does not lateralize the lesion, as is the case in extradural hematoma. A fracture may be absent or there may be a fracture in the opposite side of the skull from that of the hematoma. Two-thirds of the cases have no fracture or the fracture is on the contralateral side. An important finding is the presence of a pineal shift in those patients who have a pineal calcification. In the acute subdural hematoma, the possibility exists of signs being on the "wrong side". In these patients the paralysis or weakness may be on the same side as the hematoma. This undoubtedly results from an uncal herniation pressing the opposite midbrain against the tentorial border resulting in pyramidal tract involvement on the same side as the hematoma.



Bilateral frontoparietal perforation and temporoparietal openings are shown in *1* and *2*. In *1*, the fluid clot is being washed out by counter-drainage as shown. In *2*, the clot is more solid, necessitating the use of a small bone flap. When a bone flap is desirable the incision may be extended, as shown by the dotted line in *2*. By the use of burr openings an adequate bone flap may be formed on the affected side and the clot removed by suction and by irrigating the surface of the brain as shown in *3*. At the edges of the opening it may be desirable to pass a brain spoon immediately under the dura and by flushing the surface of the brain more clotted material may escape. In this way the larger share of the surface of the brain may be irrigated with saline with removal of most of the collection. Usually, bleeding points are not found on the surface of the brain which resulted in the formation of the clot in the subdural space. If such bleeding points are present they are dealt with by clips or electrocautery, as desired. In many cases of subdural hematoma, the clot may be semiliquid with no membrane formation, consequently, the use of drainage through two openings in the skull is adequate. It is important in all of these patients to explore both sides in order to reveal a bilateral collection. When trephine openings are placed in a pattern allowing the formation of a small bone flap, the operation is much more orderly and satisfactory, when such a step is necessary.

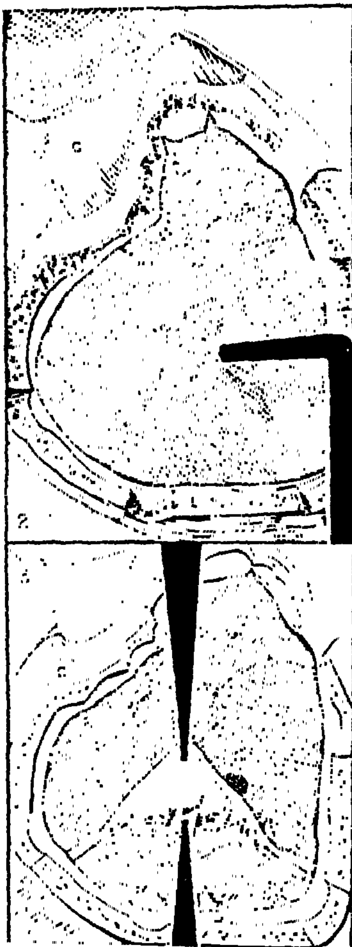
In *1*, the hematoma is being washed out by flushing of saline through the anterior opening, with escape of the collection through the temporoparietal opening. In *2*, the method of turning a bone flap, if this is more desirable after the initial exploratory openings have been made, is shown. Two additional openings are made after joining the incisions. In *3*, the bone flap has been completed. At *a*, is shown the temporal muscle and the flap more laterally. The clot is being removed from the surface of the brain by suction and by irrigation. It is important to be careful in the use of suction so as not to damage the cortex. In *4*, the use of a brain spoon passed under the dura at the bone edge is shown for the purpose of flushing out more clots that may be just beyond the opening in the skull. This may be done gently without damage to the brain and many large pieces of clotted material may be removed with ease The subdural space may be drained for twelve to eighteen hours



In some instances, a bone flap is desirable. With a subdural hematoma containing little fluid clot, a bone flap for excision of the mass is indicated Such a bone flap may be formed in the frontotemporal area as shown in *1*. Usually there is considerable bleeding as one proceeds with the operation because of the underlying pathological condition. When the bone flap is completed the exposed dura is found to be a dark blue due to the underlying collection. The dura may be opened circularly. Bleeding points may occur between the dura and the outer wall of the subdural hematoma. Usually the subdural hematoma extends only to the upper edges of the temporal lobe. The outer wall of the hematoma may now be opened and the contents aspirated. They usually include fluid portions and clotted masses. The larger clotted portions cannot be removed through burr openings.

When a bone flap has been used in the management of a chronic subdural hematoma, the external wall of the hematoma and the internal thinner membrane should be removed as completely as possible. After careful hemostasis the dura may be closed. It is important to cut the dura completely and resuture it as a free graft. Tenting of the dura at the bone edge is advisable. We usually drain the wound for eighteen hours, including the subdural area, with a flat rubber drain. In *1*, the position of the skin incision and the bone flap is shown In *2*, the outer wall of the hematoma is exposed. The temporal muscle is seen at (a). The temporal lobe is not covered with the hematoma. In *3*, the outer and the inner walls of the hematoma are being removed. As much of the lining is removed as possible without producing cortical injury, after the contents are removed by aspiration or irrigation with saline. Small portions of the hematoma wall may be left in the cranial cavity without any complications. The brain may be found markedly retracted. It is best to tap the ventricle and inject 20–60 cc. of saline. This may be life saving. Others have suggested an air encephalogram for the same purpose.

In many instances of chronic subdural hematoma a history of head injury may not be obtained, since frequently the injury may be trivial. The possibility of chronic subdural hematoma should be suspected in patients who are becoming more stuporous and who on examination of the urine, the blood NPN, the blood sugar, as well as physical examination of heart and lungs, and blood pressure, appear to be entirely within normal limits. In such a case lumbar puncture may reveal a yellowish or clear fluid, with a pressure which is high in many instances, but need not be above 150 to 200 mm of water A study of the electroencephalogram may be suggestive, but frequently this may not be diagnostic. Angiography, air studies, or exploratory trephine openings are the only way in which a definite diagnosis can be made At times, a calcified pineal may be shifted In many cases of subdural hematoma, localizing signs are few and late in appearance. At times, localizing signs may be found on the side of the hematoma, instead of the opposite half of the body In other instances, the most important com-



plaint of the patient is severe headaches which are usually unilateral. These headaches may disappear after a lumbar puncture. In post-traumatic cerebral syndrome and in mild head injury, the possibility of a chronic subdural hematoma should never be forgotten and it is best to be sure by utilizing all diagnostic procedures. Air encephalography is valuable and is unusually well tolerated by this class of patient.

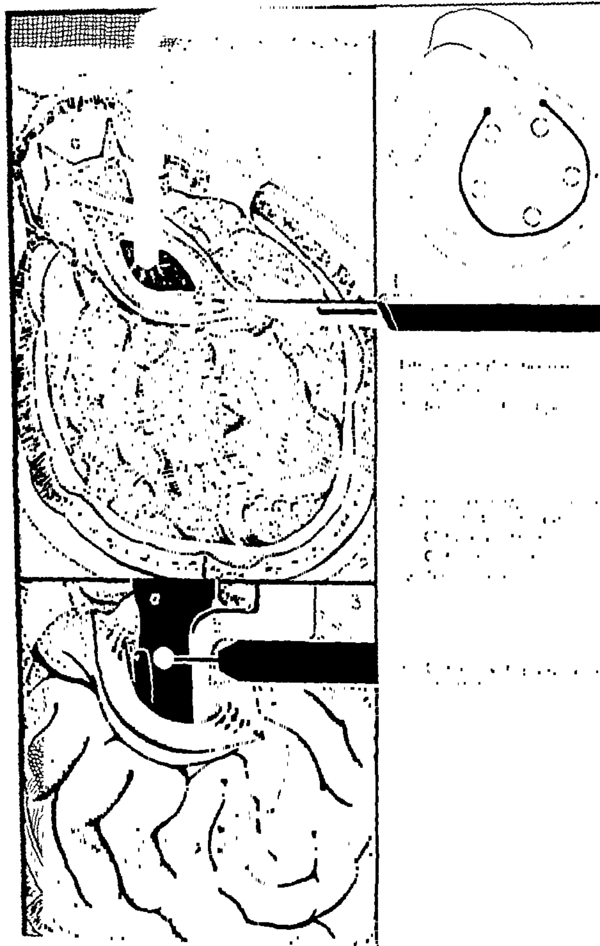
Some cases of chronic subdural hematoma can be treated by burr holes with evacuation of a liquid collection. Usually a frontoparietal opening with counter opening in the temporoparietal region effectively deals with a liquid clot with or without a membrane. The brain surface may be several cm. from the dural lining after the evacuation. In such an instance, it is best to tap the ventricle with a blunt needle and inject 20–60 cc. of normal saline. This obliterates the subdural "dead space". It is also of value in resuscitating the patient. Exploratory burr openings should always be on both sides, so as not to overlook bilateral collections. Essentially, this method of management is used in patients who have subdural collections of spinal fluid or hygroma.

## Traumatic intracerebral hematoma
## Temporoparietal intracerebral clot

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Many of the intracerebral clots are in the temporoparietal region, both of traumatic as well as spontaneous origin. A temporoparietal intracerebral hematoma and its management is diagrammed and discussed. An adequate bone flap is made to expose the parietal and temporal areas. After opening the dura one can usually note the presence of the widened and flattened superior and middle temporal convolutions. There may be yellowish to brownish and blackish discoloration of the cortex, pointing to the underlying lesion. This area may be soft on palpation and may fluctuate. A cannula may be introduced into the cystic area and xanthochromic fluid or liquid clot aspirated. After cauterizing the surface blood vessels, the fluctuant temporal lobe convolution is incised with the electrical unit as shown in 2. The cavity of the clot is entered. The clot may be removed by suction and irrigation. Fluid clot as well as some solid portions are usually present. The solid portions may line the wall of the cystic cavity. Temporal dura is seen at *a*. In *3*, the cystic cavity is projected. A lighted retractor has been introduced at *a* and at *c* a bleeding point is being coagulated with the use of forceps and electrode as shown at *b*. After hemostasis the dura is closed and tented. Drainage is used. The bone is replaced and held in place with two wire sutures. The scalp is closed in layers with interrupted fine silk.

In the acute case, focal neurological signs may identify the site of the collection when the lesion is not in a silent area. The spinal fluid may or may not be bloody, depending upon associated subarachnoid hemorrhage. Signs of increasing intracranial pressure with progression of symptoms and involvement of vital centers may suggest the presence of a mass lesion.


G
2
3

More often than not a subdural hematoma is suspected. By means of angiography the exact location and the presence of such a lesion may be diagnosed. It is particularly important to know whether one is dealing with an intracerebral hematoma, rather than a subdural hematoma, since the management of the case may be different in the two classes of patients. Such cases are somewhat confusing since with an intracerebral hematoma there may also be a small to a large complicating subdural hematoma. Consequently, the finding of subdural bleeding may stop further search for an intracerebral hematoma. If one has a preoperative knowledge of the presence of such a lesion, management is more deliberate and the search does not cease until the hematoma is found.

Intracerebral hemorrhages are mainly of two types; those which are minute, pinpoint, multiple hemorrhages, through the substance of the brain, or petechial hemorrhages, and those which are of the massive variety.

The massive variety of intracerebral hematoma, due to trauma, is usually the result of disruption of vessels in a deep contusion of the brain. In many instances the hematoma of this type includes large quantities of degenerated and necrosed brain tissue, as well as clotted material In some cases such a hematoma may be small and may not cause signs of compression. Eventually it may liquefy and a cystic cavity may form with yellowish fluid and in old cases, the cystic cavity may contain a clear fluid. At times, such a cystic area may communicate with the ventricular cavity suggesting traumatic porencephaly. The lining of the cavity is smooth and shiny. It consists of cuboidal epithelium A hemorrhage into a cyst of this type may occur secondarily from trauma or spontaneously many months or years later, resulting in signs of compression and death in some cases. Traumatic intracerebral hematomas have been reported from time to time. Such reports include those of Schwarzacher, Reuter, Craig and Adson, Naffziger and Jones[123], Browder, and others. Many of these hematomas occur in the temporal region. Frontal hematomas are next in frequency, but it is obvious they may occur in any part of the cranial cavity, including the posterior fossa and cerebellum. The diagnosis of the lesion and the exact localization may be possible by the use of air studies and angiography. Particularly, the latter promises to be of important localizing significance as concerns lesions in the frontal, temporal and parietal areas.

## Certain Neurosurgical Problems in the Infant

Epidural hematoma in infancy was considered rare. However, Campbell and Cohen have reported on twenty cases of epidural hematoma in early childhood. About half of these occurred in infants under the age of twenty

months. The remaining were distributed up to the age of twelve. The diagnostic features including drowsiness, through stupor to coma, frequently accompanied extradural hematoma in these young people. With these signs of increasing compression, trepanation was used. Note was also made that "because an extradural hematoma can be simulated by other lesions, a surgeon must not be disappointed by negative trephine openings on many occasions". The management of such lesions through a small bone flap is adequate and proper.

*Subdural Hematomas in the Infant.* Until the twentieth century, there is little information on the surgical treatment for subdural extravasations in the newborn. These lesions were noted in pathological studies only. Gross[131] in the latter part of the nineteenth century clearly described such lesions and suggested evacuation of the clot.

Subdural hemorrhages may result from birth injuries, injuries by forceps, falls and other trauma. In the acute subdural hemorrhage the infant does not react normally to its environment, presenting often lethargy with dull responses to stimuli. A weak, inconstant cry replaces the lusty ability of the normal infant. Cyanosis may appear with weak, irregular respirations. High concentrations of oxygen may have little effect. Neurologic findings may not be convincingly demonstrated. Occasionally there may be bilateral or unilateral spasticity; pupillary inequalities may sometimes occur. Convulsions are common and they may be either generalized or localized. An important finding is a tense, full and boggy fontanel. Lumbar puncture may show the presence of grossly bloody spinal fluid or xanthochromic fluid. The infant who has weathered the acute form of the subdural hematoma and has developed a chronic type of the lesion or a hygroma, may progress satisfactorily in the early months until a parent or the pediatrician may notice enlargement of the head. In some patients there may be a convulsive seizure. A cracked-pot sound may be noted upon percussion of the head, as noted by Peet and Kahn. Although the general appearance of the child may suggest hydrocephalus, yet the physiognomy and the facial expression is not that of a hydrocephalic and the child appears to be much more intelligent, and more responsive to its environment than a hydrocephalic child The fontanel may be often enlarged, the sutures may be separated as shown by roentgen studies. The collections in the subdural space may vary from clear to xanthochromic to bloody collections. There may be a pseudomembrane or the fluid may be merely encased by the dural and arachnoid linings without any pseudomembrane surrounding the collection. Although a subdural collection of clear or xanthochromic fluid can be effectively emptied through one single or two trephine openings, a subdural collection with a pseudomembrane is better treated by a small bone flap with excision of as much of the membranous material as possible.[211]

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SPINE

# Historical Notes on the Surgery of the Spinal Cord

EARLY historical records indicate a recognition of the relationshi between vertebral injury and paralysis. Early treatment was de signed to reduce obvious deformities by closed methods. Ope methods in the treatment of vertebral injury were rarely used. Discouragin results attended all types of treatment.

A close parallel may be found in the philosophy of surgical treatment fo spine and cranial injuries. This becomes apparent in the 19th century whe through surgical progress, spinal cord injuries were reevaluated. Sha asked the question in 1861, "Is it possible by an operation upon the spin similar to what is performed on the skull, to restore the functions of the cord It has been proposed, and surgeons at various times have carried the pro posal into effect, to make an incision along the back and with the trephine bone scissors, levers and forceps to extract depressed fragments of vertebra from the posterior surface of the spine". He stated that the objections urge against this formidable treatment far surpassed in weight arguments o testimony brought in its favor. Shaw pointed out that at the time of injur the cord suffered irreversible damage from which it could not be relieved b surgical decompression; that cord damage was due to "the fragments of th broken vertebrae which are indented into the cord and commit the greates injury are in front and not behind. It does not appear therefore that benef can possibly be gained so long as the principal cause of compression continue to exist on the forepart by extracting portions of the posterior arches".

Dr Brown-Séquard was a proponent for operation, believing that surger "ought to be employed in almost all cases of fracture of the spine, especiall in the cervical region". He stated that "if after having laid bare the spin cord it is found necessary to reduce a fracture of the body of one or severa vertebrae, the reduction will then be much easier and attended with muc less danger than if the vertebral canal had not been opened on its bac part". Shaw disagreed with this concept and advised, "Let the youn surgeon's mind therefore be fortified against the influence of the authorit in favor of operation given by certain great men in the profession; let hi feel assured that in abstaining from performing it, his forebearance is n neglect but a positive duty to his patient".

In the treatment of closed injuries to the spine with fracture of the vertebra, Gross[33] also held that, "little could be accomplished in restoring displaced fragments or function". He stated that "this was applicable to the operation of cutting down upon the injured part and removing the affected portion of bone with the trephine or saw as originally suggested by Paul of Aegina and first practiced in 1814 by Mr. Henry Cline of London. Of thirty-eight cases tabulated by Dr. John Ashhurst in which this procedure has been employed, including those of Barton, Rogers, Potter, Blackman, Hutchinson and Stephen Smith, twenty-nine died, three were relieved, two were not benefited and the result is unknown in four".

Gross[34] briefly mentioned that carcinoma of the vertebra was treated by palliative methods, stating that "all that can be done is to alleviate pain and to smooth the patient's passage to the grave". Erichson points out that the operation of trephining the spine was originally proposed by Heister and first performed by Cline.

The type of surgical procedure reported as being done in this period was carried out by an incision 3 to 5 inches in length at the site of the injury. "The muscle masses on either side of the spine are dissected away so as to expose the osseous surfaces. The spinous processes at the seat of injury should then be successively seized with strong forceps, and gently but firmly moved in order to see whether there be fractures at their base or supporting arches. If a portion of bone be completely broken off, it may come, after all ligamentous connections have been severed, and be raised by a forceps or an elevator. Should one arch only be broken through the uninjured one may be divided by cutting pliers or a Key's saw; or should both be unbroken the surgeon may, if he thinks it prudent to proceed further, divide both in this way and so remove them and the spinous process and expose the theca of the cord".

The treatment of open war wounds involving the spine was equally, if not more, discouraging. An added element which produced an early fatal outcome was that of inflammation not present in closed wounds involving the vertebrae. Gross[34] stated, "gunshot wounds of the vertebrae with lesions of the spinal cord are nearly always, if not invariably, fatal. Of twenty-two cases of this kind in the English Army in the Crimean War, not one recovered". Dr. Otis reported one hundred eighty-seven cases of gunshot fractures of the vertebrae which occurred during the Civil War which, with the exception of seven, proved fatal. Gross[34] stated that, "in the treatment of wounds in the spinal cord the great object should be to moderate inflammation and to prevent effusion and other ill effects. If foreign matter be present, pressing upon the cord, it should, if possible, be removed although in attempting to do this there may be great risk of increasing the original mischief Trephine will not be likely to be of any service. The operation, which has been tried in a number of cases in depressed fracture of the vertebrae, seldom has been productive of the slightest benefit".

The modern period for spinal cord surgery comparable to that for intracranial operations is dated by a series of successes which in turn depended

upon the advent of antisepsis and increased knowledge of neurology. Notable success in spinal cord surgery was first reported by Macewen who stated that "the spinal membranes of the cord itself could be exposed and neoplasms and encroachments upon the lumina of the canal may be removed therefrom without unduly hazarding life" (1888). He stated that "the first operations of this kind were undertaken by me for the relief of paraplegia due to angular curvature of the spine". This was carried out successfully in 1883. This success involved a nine-year-old boy who "was suffering from complete sensory and motor paraplegia which has existed for two years and was absolute during the last eighteen months". On May 9, 1883 the laminae of the 5th, 6th and 7th dorsal vertebrae were removed. A fibrous neoplasm was dissected off. The cord was able then to expand backwards and its pulsations, which up to this period were absent, began to show themselves. Six months subsequently the patient was able to walk without support. Five years later he went to school and joined in games, etc. Horsley[17], associated with Gowers, has been credited with deliberately exposing the spinal cord for the removal of a tumor, with a successful outcome. Rapid advance followed these early efforts. Krause pointed out that all forms of paralysis of the spinal cord in which partial or complete interruption of conduction is caused by trauma, or by compression of the cord, were subjected to surgical treatment at his clinic. He found that the number of successful cases so treated increased each year. He attributed these successes to the refinement of surgical technique and to the progress made in the treatment of wounds. Credit also was given to "the extraordinary attainments in the field of diagnosis in the last decade or so during which not only the diagnosis of the existence of a tumor was made possible but we were in many cases successful to exactly locate the site of the neoplasm by means of the so-called segmental or level diagnosis".

The chisel was employed by Krause in the early successful exposures of the spinal cord. The arch of the respective vertebra "is first carefully divided at one and then the other side with a chisel not too distant from the spinous process. While the latter is seized with a forceps and strongly pulled upon, the soft tissues still attached to it, especially the strong intercrural and interspinal ligaments are divided. The chiseled median portion of the arch may now be completely detached with a few snips of the scissors, and the vertebral canal is now exposed to view in the depth of the retracted wound. The lateral remnants of the arch are removed with rongeur forceps. The division of the adjacent arches is facilitated by introducing a thin, curved elevator through the vertebral canal in an upward direction and under its *protection* the arches are cut through; the sharp borders are ronguered off with the rongeur forceps" An improvement in Krause's technique substituted the "laminectome" for the chisel. This instrument was built on the principle of the Dahlgren forceps. By this method, "on either side of the exposed spinous processes, an opening is drilled with a Doyen instrument carrying a medium sized burr. I now carefully introduce the cutting hook of the laminectome into the opening and insinuate it underneath the arch and while the embracing fork

of the other arm of the forceps steadies the hook by pressure upon the long upper lever, the arch is cut through. A preliminary detachment of the dura mater, as practiced on the skull, is here unnecessary because a layer of epidural fat of greater thickness separates it from the inner surface of the arches. The same maneuver is then carried out on the opposite side".

Krause also used a method of removing the entire posterior wall of the vertebral canal in one piece. To accomplish this Krause bored a hole on either side of the spinous process of the uppermost or lowest arch to be resected and then he made two parallel incisions with the "laminectome" which divided the osseous substance of the arches and the intervening ligaments and the entire posterior wall of the vertebral canal was thus removed in one section. An advantage of the cutting hook was that there was little bleeding from the cut surface of the bone. Krause favored the cutting hook to the commonly employed Horsley large cutting forceps An alternative method described by Krause was that "the spinous processes and posterior arches may be taken away piece-meal with rongeur forceps of various sizes and shapes, a procedure against which nothing can be said except that it is tedious".

Opinion was at first divided between the use of a laminectomy or an osteoplastic resection of the overlying bone in exposing the spinal canal. There were adherents to both methods. The argument for osteoplastic resection was presented by Bickham who stated, "It is not open to question that the laminectomy leaves a weaker spine than does the osteoplastic resection, for the latter leaves a practically intact spine, while the former leaves a spine minus as many spinous processes and laminae and their connecting ligaments, as have been cut out. Just how much weaker a laminectomy leaves the spine it would be hard to calculate; but it is self evident that a whole spine is better than part of a spine, even if only one-quarter or one-third of two or three vertebrae have been permanently removed". When it was found however that the patient was able to sit upright and support his head following laminectomy, without necessitating the wearing of a support, this and the advantage of greater simplicity resulted in adoption of the laminectomy and hemilaminectomy Woolsey, at the turn of the century, stated that " the simplest technique is the best. The osteoplastic method such as Urban's, Abbe's, or Bickham's, should accordingly be discarded. They offer no advantage, take a longer time, and the laminae add little if anything to the strength of the spine and do not bear any of the weight carried by it" Elsberg[2], by 1916, presented a standardization of techniques in spinal cord surgery which endured. Other important contributors in the early part of the century included Bonomo who first suggested the hemilaminectomy (1902)

The saws and trephines were discarded and replaced by single-acting rongeurs Elevators were used in place of chisels and a self-retaining retractor was used for exposure in place of hand retractors A large single-acting gouge rongeur was used for removal of the spinous processes, while a smaller type of rongeur of the Horsley type was used for the laminae For widening the spinal opening a straight Taylor gouge-type of rongeur was used.

# Certain Points About the Vertebral Column and Vertebral Articulations

THE VERTEBRAL column is made up of thirty-three vertebrae, seven in the cervical region, twelve in the thoracic, five in the lumbar, five in the sacral and four in the coccygeal area. In adult life the sacral and coccygeal vertebrae are united to form two bones, the sacrum and the coccyx. These are called fixed or false vertebrae, as compared with true or movable vertebrae in the remaining vertebral column.

The general characteristics of a vertebra include the body or the anterior portion and the neural arch or the posterior part. The neural arch or the vertebral arch, which encloses the vertebral foramen, consists of a pair of pedicles, two laminae, two transverse, four articular and one spinous processes. Between consecutive vertebrae are intervertebral foramina on either side, and these intervertebral foramina are made up of vertebral notches of the pedicle above and below.

The pedicles are short, thick, posterior projections of bone from the body of the vertebra, one on either side. The laminae are attached to the pedicles and extend medially and fuse with each other posteriorly. From the area of fusion of the laminae there arises the spinous process which extends usually posteriorly and inferiorly. The laminae are thin and flat in the cervical and upper thoracic regions. They are thickened and more rounded in the lower dorsal and lumbar regions.

The articular processes, of which there are two superiorly and two inferiorly for each vertebra, arise at the junction of the pedicle and laminae. Superiorly, they articulate with the inferior articular processes of the vertebra above Those inferiorly articulate with the superior articular processes of the vertebra below.

The transverse processes, of which there are two, arise from the junction of the lamina and pedicle laterally, between the superior and inferior articular processes In the cervical region they are traversed by the intratransverse foramen which houses the vertebral vessels. The transverse processes of the 2nd to the 10th thoracic, inclusive, have articulating surfaces with the tubercle of the upper ten ribs.

Spinous processes in the cervical region are characterized by the presence of a bifid termination This is true from the 2nd to the 6th, inclusive. On the

1st cervical vertebra there is no spinous process, its place being taken by the posterior tubercle in the posterior median portion of the posterior arch The 7th cervical has a single bulbous termination. The direction of the spinous processes varies in different regions. In the cervical region they extend posteriorly and slightly downward; in the thoracic region the downward extension of the spinous process is accentuated, particularly in the mid-thoracic area. In the lumbar region the spinous processes are flat, and they extend posteriorly, with only a slight inclination downward. On the sacrum the spinous processes are posterior extensions of bone forming the medial-sacral crest.

The 1st cervical vertebra has no body. Instead, it has an anterior arch with which the odontoid process of the 2nd cervical vertebra articulates.

### ARTICULATIONS

The bodies of the vertebrae are held together with the anterior and posterior longitudinal ligaments and the intervertebral fibrocartilages. The ligamentum flavum, the supraspinal ligament which is the ligamentum nuchae in the neck region, the interspinal and intertransverse ligaments and the articulations of the articular processes join together the vertebral arches.

The ligamenta flava are attached to the laminae of adjacent vertebrae. They are found from the 2nd cervical to the 1st sacral laminae. They are attached to the posterior surface at the junction of the pedicle with the body and the lamina to the spinous process, each ligamentum flavum on the two sides uniting at the midline. They extend up and are attached to the anterior surface of the lamina above. The ligamenta flava are thickest in the lumbar region. Microscopically they are made up of yellow elastic connective tissue.

### ARTICULATIONS OF THE OCCIPITAL BONE, 1ST AND 2ND CERVICAL VERTEBRAE

The posterior atlanto-occipital membrane and the posterior atlanto-axial ligaments are structures which are encountered posterior to the dura, at the craniospinal junction. The posterior atlantooccipital membrane extends from the lower border of the occipital bone about the foramen magnum to the upper and anterior border of the posterior arch of the atlas. The atlanto-axial ligaments are attached to the lower border of the posterior arch of the atlas and extend down to be attached to the upper border of the lamina of the axis.

The odontoid process of the axis is held in position against the anterior arch of the atlas by the transverse ligament which extends from the internal aspect of the lateral mass of the atlas on one side to the lateral mass of the atlas on the opposite side. This in turn is covered by the upward extension of the posterior longitudinal ligament or the so-called membrana tectoria, extending from the region of the body of the 2nd cervical to the basilar portion of the occipital bone above the foramen magnum, becoming continuous with the endosteal layer of the cranial dura.

## The Intervertebral Disc

Intervertebral discs are found between consecutive vertebral bodies, beginning with the 2nd and 3rd cervical vertebrae, and ending at the sacrum. The discs are somewhat thicker in the anterior portion, than posteriorly toward the vertebral canal, in the sacral and lumbar area. In the thoracic region they are about the same thickness anteriorly and posteriorly. One-fourth of the length of the vertebral column is made up of intervertebral discs. Intervertebral discs are attached to adjoining vertebrae. The body of the vertebra superiorly and inferiorly is covered with a thin layer of hyalin cartilage. Intervertebral discs are attached to the anterior and posterior longitudinal ligaments anteriorly and posteriorly.

Microscopically, the intervertebral disc is made up of the annulus fibrosus, which is a white fibrous cartilage surrounding a pulpy and soft nucleus pulposus, which is in a central location. The annulus constitutes the lateral boundary of the intervertebral disc.

## The Ligamentum Nuchae

The ligamentum nuchae is the supraspinal ligament in the neck area. Superiorly, it is attached to the external occipital protuberance and the median nuchal line. Inferiorly, it extends down to the 7th cervical vertebral spinous process. It is also attached to all the spinous processes of the other cervical vertebrae, including the posterior tubercle of the atlas, thus forming a septum between the muscles on either side of the neck.

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# The Spinal Cord

IN THE adult the spinal cord extends from the foramen magnum to the middle of the second lumbar vertebra. It is a circular or oval-shaped structure showing two enlargements, one in the cervical region and one in the lumbar area. The cervical enlargement, extending from about the fourth cervical to the second thoracic segment, mediates the afferent and efferent impulses to the upper extremities; whereas, the lumbar enlargement, which extends from the twelfth dorsal to the second sacral segment is responsible for afferent and efferent impulses of the lower extremities. The pia of the spinal cord continues as the filum terminale internum below the level of the cord to the second sacral spine where the dural sac terminates. Outside of the dural sac it is continued as the filum terminale externum The spinal cord is held in position by the nerve roots, the dentate ligaments and the filum terminale. The denticulate ligaments are triangular structures of pia with the base of the triangle on the side of the spinal cord, with the apex of the triangle extending through the arachnoid cavity and attached to the inner surface of the dura. The dentate ligaments lie between the anterior and the posterior roots of the spinal nerves. There are twenty-one pairs of dentate ligaments. At two months of fetal life the spinal cord completely fills the spinal canal. With further development the bony growth is more accelerated than that of neural tissue so that the lower end of the spinal cord eventually ends at about the middle of the second lumbar vertebra. This results in longer nerve roots in the most caudal portions of the spine. At the lower end of the spinal cord these nerve bundles, extending to their respective intervertebral foramina, constitute the cauda equina.

There are thirty-one pairs of nerves There are eight in the cervical, twelve in the thoracic, five in the lumbar, five in the sacral, and one or two in the coccygeal regions. Each spinal nerve passing through an intervertebral foramen is the product of a dorsal root and a ventral root except the first cervical in which the dorsal root is usually absent, and there is a relatively large ventral root.

The spinal cord is surrounded by dura, arachnoid and pia mater. There is a potential space between the dura and the arachnoid membrane, there is a real space between the arachnoid and the pia mater—the subarachnoid space. This space is trabeculated with fine projections of arachnoid tissue crossing it from the arachnoid to the pia, and vice versa. The lumbar cistern

is the large subarachnoid space occupied by cerebrospinal fluid in the lumbar area. The dura and contents are housed in the spinal canal. Immediately on the outside of the dural lining is the epidural space which is filled with fatty tissue and blood vessels. This epidural fat is much more compact on the dorsal surface of the dura than on the ventral surface.

The spinal cord contains ascending and descending pathways and gray matter which is in a central location. The spinal nerves which mediate the afferent and efferent stimuli, somatic and visceral functions, are made up of ventral and dorsal roots. The dorsal root, which arises from the dorsal ganglia, contains sensory fibers. The ventral root contains both somatic and visceral motor fibers. The latter are the preganglionic fibers to the sympathetic system. The somatic motor fibers arise from the anterior horn cells and the visceral motor fibers arise from the intermediate gray matter or the lateral horn which is best developed in the dorsal area.

The sensory fibers from the periphery have their cells of origin in the dorsal ganglia. These ganglion cells give rise to a single process which divides immediately into a dendrite from the periphery constituting a sensory nerve fiber and an axon which extends to the spinal cord. These axons going to the spinal cord in the dorsal root are made up of thick myelinated fibers found in the medial portion of the root and thin nonmyelinated fibers which are in a lateral position in the dorsal root. The thick myelinated medial fibers are mainly for proprioception; whereas, the lateral fibers are mainly for pain and temperature and light touch. There are some intermediate fibers which are thinner than the medial group and thicker than the lateral fibers, and they help form the spinocerebellar pathways. The general pattern of the sensory axons is as follows: The fibers in the medial portion of the root enter the gracilis or cuneate areas, divide in a T-fashion with long ascending and short descending branches. The long ascending fibers make up the gracilis and cuneate bundles in the posterior column. The short descending fibers form the septomarginal fasciculus in the lower dorsal and lumbar areas and the comma tract or the interfascicular fasciculus in the cervical area. The intermediate and the lateral portions of the dorsal root fibers extend up or down for two to four segments and then they end about the cell bodies in the dorsal horn, or the substantia gelatinosa. From these cell bodies fibers arise which cross to the opposite side in the anterior commissure and then ascend in the ventrolateral column as the lateral spinothalamic tract, mediating pain and temperature. Other fibers of the dorsal root end about the cell bodies of the Clarke's column in the gray matter of the dorsal horn of the spinal cord. Fibers from the column of Clarke then extend to form the dorsal spinocerebellar fasciculus on the same side and still others, arising from cells in the dorsal column form the ventral spinocerebellar fasciculus of the same and opposite sides.

The descending pathways are mainly for *qualifying* the activities of the anterior horn cells or the motor cells of the spinal cord. The most important of these is the lateral corticospinal *fasciculus* or the pyramidal tract. Other fasciculi are the lateral reticulospinal, the rubrospinal, the lateral tecto-

spinal, the viscero-bulbo-spinal, the dorsal vestibulospinal, the medial tecto-spinal, the ventral vestibulospinal, the ventral reticulospinal tract, the ventral corticospinal, and the sulcomarginal. These are shown in the accompanying diagram (Mettler[18a, 308a]).

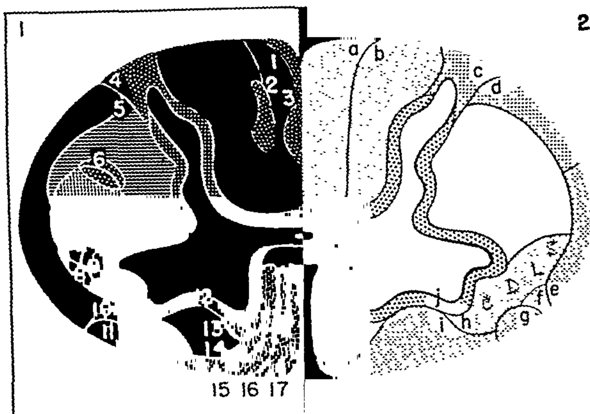
From the surgical standpoint it is important to keep in mind that in the anterolateral column the lateral spinothalamic tract has the sacral fibers on the outermost portion of the spinal cord; whereas, the fibers from the lumbar, the dorsal and the cervical areas are respectively in a more antero-medial position toward the anterior horn. In the case of the dorsal column, the fibers in the gracilis bundle are from the lower portion of the body; whereas, those in the cuneate fasciculus are from the thoracic and cervical regions. The deepest fibers or those closest to the gray matter of the spinal cord, of the lateral corticospinal tract or the pyramidal tract, are those that mediate the lumbar and sacral areas; whereas, the outmost fibers are those that supply the cervical region.

The visceral efferent fibers from the spinal cord or the preganglionic sympathetic fibers have their cells of origin in the lateral column of the spinal cord in the thoracic, and the upper lumbar region. Those in the sacral region belong to the parasympathetic system and their cells of origin are not as discrete as in the thoracic area. All these preganglionic fibers leave the spinal cord in the anterior roots.

## Blood Supply of the Spine

The arterial supply of the spine, the spinal cord and the dorsolateral muscles of the spinal column is segmental. In the cervical area the ascending cervical, the descending branch of the occipital, the deep cervical and the vertebral arteries supply these structures The upper two intercostal vessels, branches of the costocervical supply the neighborhood of the upper two dorsal vertebrae and spinal cord. The remaining dorsal area is supplied by the intercostal arteries, while the lumbar region is supplied by the lumbar arteries and the sacral region by sacral arteries.

The bony structures and the muscles are supplied by the vertebral, the ascending cervical, the deep cervical, the descending branch of the occipital in the neck. In the dorsal area the dorsal branch of the intercostal artery supplies the vertebral bony structures and the posterolateral muscles about the vertebrae. The dorsal branch of the intercostal gives off the radicular branch to the spinal cord which traverses through the intervertebral foramen and extends into the canal to supply its contents. The dorsal branch of the intercostal ends in a medial terminal branch and a lateral branch. The medial terminal branch extends posteriorly along the lateral aspect of the spinous process all the way to the lumbodorsal fascia and after supplying many twigs to bone and muscles it enters the subcutaneous tissue and sup-




Descending Paths
Left Side

1. Dorsal cervicolumbar descending tract.
2. Interfascicular tract (descending).
3. Septomarginal tract (descending).
4. Lissauer's tract.
5. Lateral corticospinal tract.
6. Lateral reticulospinal tract.
7. Rubrospinal tract
8. Lateral tectospinal tract.
9. Solitariospinal tract
10. Dorsal vestibulospinal tract.
11. Olivospinal tract
12. Ascending and descending reticulo-spinal tract
13. Ventral reticulospinal tract
14. Medial tectospinal fasciculus.
15. Ventral vestibulospinal fasciculus.
16. Ventral corticospinal tract.
17. Sulcomarginal fasciculus.

Ascending Paths
Right Side

a. Fasciculus gracilis.
b. Fasciculus cuneatus.
c. Dorso-lateral fasciculus
d. Dorsal spinocerebellar tract.
e. Ventral spinocerebellar tract.
f. Spinotectal tract.
g. Spino-olivary tract.
h. Lateral spinothalamic tract.
i. *Ventral spinothalamic tract.*
j. Spinoreticular tract.

plies the skin. The lateral terminal branch is mainly muscular and it extends between the iliocostalis and the longissimus muscles, becoming subcutaneous and supplying the skin. The arterial distribution is essentially the same in the dorsal, the lumbar and sacral areas.

The spinal cord and the contents of the spinal canal receive their arterial supply from the anterior and posterior spinal arteries which arise from the vertebral, and the lateral spinal arteries or radicular spinal arteries which come in to the spinal canal through the intervertebral foramina at various levels. The radicular branches entering the spinal canal divide into posterior and anterior branches which follow the course of the posterior and anterior roots. The posterior branch becomes continuous with the posterior spinal artery proper on the side of the radicular vessel. The anterior branch extends to the anterior spinal artery and here it becomes continuous with the fellow on the opposite side through the anterior spinal artery. From the two posterior spinals and the single anterior spinal arteries several branches are given off which extend into the substance of the spinal cord. The anterior spinal is the main supply to the gray matter of the spinal cord. The anterior and the intermediate horn are supplied by this vessel.

The arterial supply of the dura and the bone is through branches given off from the radicular vessels and these branches course in the epidural space and fat. Basivertebral arteries supply the bodies of the vertebrae.

The venous drainage of the spinal cord, the spinal canal, the vertebrae, as well as the dorsolateral spinal muscles can be summarized as follows: From the substance of the spinal cord tributaries empty into the posterior central and anterior central veins as well as the posterior external and anterior external veins. These, in turn, empty into the posterior and anterior radicular veins which unite to form the radicular veins. From the cervical region the radicular in turn empty into the vertebral plexus of veins and thence into the internal jugular vein

The vertebrae and the dura are supplied with the posterior internal venous plexus and the anterior internal venous plexus. Into the latter empty the basivertebral veins which come from the bodies of the vertebra proper. The anterior external venous plexus and the posterior external venous plexus drain the external portions of the vertebrae and join the intervertebral veins which in turn empty into the vertebral plexus in the cervical region. In the upper four thoracic region, on the right side, the intervertebral veins empty into the intercostal veins and they in turn empty into the azygos and the superior branch of the azygos or superior intercostal vein, whereas, from the 4th to the 12th they empty into the azygos proper. On the left side, from 1 to 6, they empty into the highest intercostal vein and from 6 to 12 they empty into the hemiazygos and the azygos veins. In the lumbar region, from the level of the 1st to the 4th, the intervertebral veins empty into the ascending lumbar vein which in turn empties into the inferior vena cava. The 5th lumbar region is drained through the iliolumbar vein which empties into the common iliac vein thence into the inferior vena cava

The arterial supply to the muscles in the neck is through the thyrocervical

trunk, the ascending cervical, the costocervical trunk, the deep cervical and the descending branch of the occipital arteries. In the thoracic region the posterior branch of the intercostal artery supplies the arterial needs of the posterolateral muscles; whereas, in the lumbar region, the posterior branch of the lumbar arteries and the posterior branch of the iliolumbar supply this neighborhood.

The musculature in the cervical area is supplied with the external jugular, the deep cervical and the occipital veins, as well as the vertebral plexus. These form an intricate plexus of veins draining the entire neck region. Eventual drainage is into the internal jugular vein. In the thoracic region the musculature is drained by the posterior branch of the intercostal veins, eventually emptying into the azygos system and the superior vena cava. In the upper four lumbar areas the lumbar veins through the posterior branch drain into the ascending lumbar and thence the inferior vena cava; whereas, the 5th lumbar region is drained by the iliolumbar vein extending into the common iliac and thence into the inferior vena cava.

In doing a hemilaminectomy or laminectomy, vessels encountered at the midline arise from the medial terminal branch of the dorsal division of the lumbar or intercostal arteries in the lumbar and dorsal regions. In the cervical areas these are branches of the deep cervical and the descending branch of the occipital and the ascending cervical arteries. The veins which are encountered are tributaries to the intercostal and lumbar veins in the dorsal and lumbar areas. In the neck they are tributaries of the occipital, deep cervical and external jugular veins.

In the accompanying diagram the venous drainage, the arterial supply, the cross-sectional view of the important muscles of the back in the posterolateral aspect of the spine and the blood supply of the spinal cord are shown.

In *1* is seen a cross-section at the level of the 4th cervical. On the left side are shown the various muscles on the posterolateral aspect of the spine. The group represented by *a* includes the trapezius, the splenius capitis, the semispinalis capitis and the longissimus capitis, naming them from the posterior aspect and extending internally. The muscle group around *b* is represented by the semispinalis cervicis and the multifidus muscles. More laterally the longissimus cervicis and the splenius cervicis muscles are diagramed in part. The ligamentum nuchae is found between the two groups of muscles on either side and at the midline where *g* shows the occipital vein. On the right, in *1*, is shown the venous drainage of the spinal cord and the posterior neck. At *c* and *c* are seen the anterior external venous plexus and the basivertebral, the latter coming from the bodies of vertebrae. At *d* and *d* the anterior internal venous plexus and the posterior internal venous plexus are shown The intervertebral vein *e* goes out of the spinal canal through the intervertebral foramen and empties into the vertebral plexus about the vertebral artery which is shown at *j*. At *f* is found the posterior external venous plexus which veins are those that

is performed in the cervical area These

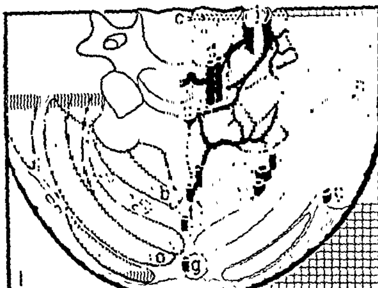
of the bifid spinous processes of the upper six cervical vertebrae. At *g* and

*g* the occipital vein, artery and nerve are shown. The accessory nerve and the vessels in the body of the sternocleidomastoid muscle are shown at *h*. The deep cervical artery and vein, medial to which is the third cervical nerve, are seen at *i*.

In *2* the musculature and blood supply at the level of the 6th dorsal is shown. At *a* is the trapezius muscle and at *b* are the longissimus dorsi, the spinalis dorsi and the multifidus muscles in that order, beginning externally and extending toward the lamina and the spinous process. At the right is shown the venous drainage of the musculature, the vertebrae, and the spinal canal. The posterior tributary of the intercostal vein is shown at *d* which receives the radicular vein as well as the medial and lateral terminal veins from the dorsolateral group of muscles and the spine. These veins accompany the arteries and the medial terminal vein hugs the spinous process and the lamina of the vertebra; whereas, the lateral terminal vein courses between the iliocostalis and the longissimus muscles. Both the arteries and the veins supply the skin. The dorsal branch of the intercostal artery, in company with the vein, course between consecutive transverse processes. At *c* is shown the azygos vein which receives the intercostal veins on the right.

In *3* is a cross-sectional representation at the level of the 4th lumbar vertebra. To the left are shown the multifidus at *f*, the iliocostalis and the longissimus dorsi at *g*, the quadratus and the psoas at *h*. The aorta at *a* is giving off the lumbar arteries, the right being longer than the left. The lumbar artery gives a dorsal branch which sends a radicular twig into the intervertebral canal, the dorsal branch then divides into a medial and lateral terminal branch. The medial terminal branch extends up along the lamina and the spinous process and the underside of the skin, after piercing the lumbodorsal fascia supplying branches to the integument. The lateral terminal branch extends up toward the posterior skin, between the iliocostalis, and the longissimus dorsi supplying branches to muscles and the integument.

In *4* is given the arterial supply on the right and the venous drainage on the left. The radicular vein on the left receives tributaries from the anterior internal venous plexus and the basivertebral veins, as well as the tributaries from the spinal cord, the posterior and the anterior spinal veins, which accompany the posterior and the anterior roots. The vein accompanying the anterior root, drains the anterior external spinal vein, the one accompanying the posterior root drains the postcentral vein and the posterior external spinal vein as shown at *b* and *c*. The posterior internal venous plexus is shown at *d* which also empties into the intervertebral vein. On the right side is shown the arterial circulation; the radicular artery sends a branch to the laminar area which is called the prelaminar branch at *d* and the basivertebral artery shown at *a*. The branches accompanying the anterior and the posterior roots supply the anterior central artery at *b*, the posterior central artery at *c*, as well as the posterolateral spinal artery just lateral to *c*.

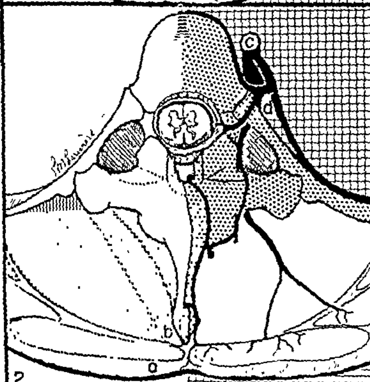


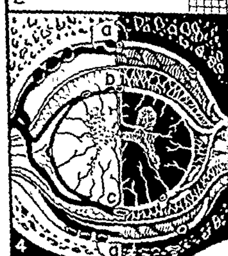

1a Trapezius, splenius capitis, semispinalis capitis, longissimus capitis b Semispinalis cervicis and multifidus c-c. Basivertebral and anterior external venous plexus. d-d. Anterior internal and posterior internal venous plexus e. Intervertebral vein f. Posterior external venous plexus. g Occipital vein. h. Accessory nerve and vessels. i Deep cervical j. Vertebral veins.

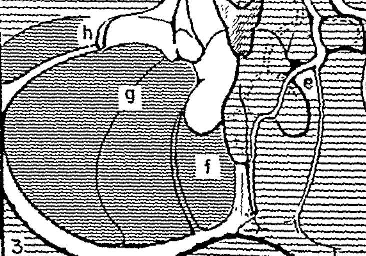
2a. Trapezius. b. Longissimus dorsi, spinalis dorsi and multifidus. c. Intercostal vein. d. Anterior and posterior branches of intercostal vein.

3a Aorta b Lumbar artery. c. Dorsal branch. d Anterior branch of lumbar e. Medial and lateral terminal branches. f Multifidus. g. Longissimus dorsi, iliocostalis. h Quadratus, psoas.

4. Right, arterial, left, venous.
a Anterior internal venous plexus basivertebral and to spinal ramus.
b. Anterior external spinal, anterior central artery and vein. c. Posterior central, posterior external artery and vein d. Prelaminar branch of spinal ramus and posterior internal venous plexus



▶

*A* shows *the relation of spinous processes, segments* of spinal cord and bodies of vertebrae.

*B* is the sensory chart of the *right half of the body viewed from the* anterior aspect.

*C* is the sensory chart of the right half of the body viewed from the posterior aspect.

## Relation of the spinous processes, spinal cord segments and dermatomes. Sensory chart of the body

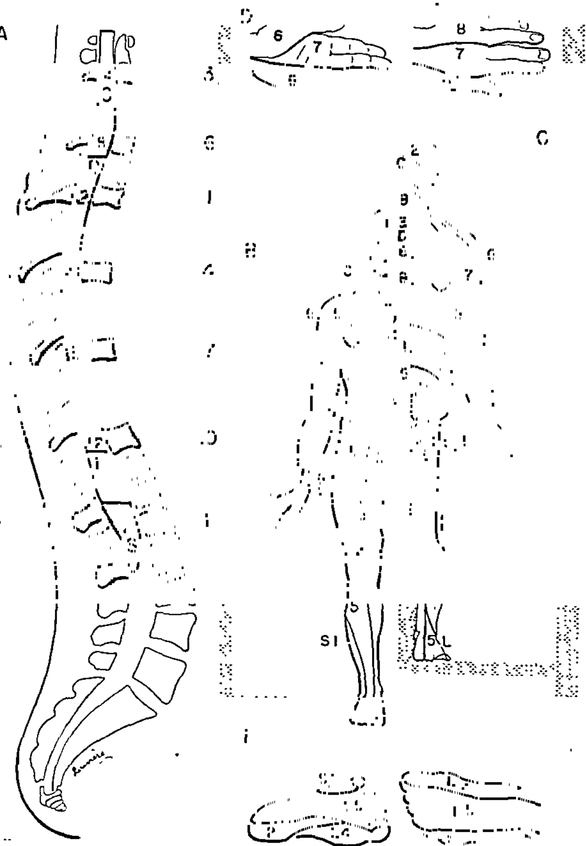
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*D* is the sensory distribution of the hand ventrally and dorsally. The *numbers indicate cervical segments of the spinal cord.*

*E* is the sensory distribution of the foot, plantar and dorsal surfaces.

While at the end of the second month of fetal life, the *spinal* cord completely fills the spinal canal, later on, due to a more accelerated growth of the bony structures, the spinal cord ends at the lower end of the 1st lumbar or the upper end of the 2nd lumbar vertebrae. In addition to this, there is a discrepancy in the number of cervical vertebrae and cervical spinal nerves, there being 8 cervical spinal nerves, with 7 cervical vertebrae. The various segments of the spinal cord are in closer relationship to the adjacent vertebrae in the cervical region, but as one goes lower down toward the lumbar area, the relationships change markedly. In general, the following is a good *working relationship. The eighth cervical segment of the spinal cord is under* the lower border of the *sixth cervical* spine, while the twelfth dorsal segment of the spinal cord is under the spinous process of the ninth dorsal vertebra. The fifth lumbar segment of the spinal cord is opposite the twelfth dorsal spinous process The sacral segments of the spinal cord are opposite the lower end of the twelfth dorsal and all of the first lumbar and the uppermost portion of the second lumbar vertebra. The coccygeal portion of the spinal cord is rudimentary

The dermatomal sensory distribution of the trunk, the upper and the *lower extremities, shown in the accompanying figure are* based upon the work of Keegan and DeJong. Of particular interest is the division of the dermatomal distribution of sensation in the lower extremities It should be noted that the 1st dorsal sensory supply is in juxtaposition to the 8th cervical on the medial aspect of the upper extremity. The second dorsal also supplies a portion of the *medial* upper aspect of *the* upper *limb in the arm* and in the axillary regions. In the lower extremity, the 4th lumbar segment supplies the *medial half of the great toe, while the 5th lumbar,* the lateral half as well as the adjoining three toes. The 1st sacral supplies the outer one to one and a half toes of the foot. The sensory representation of the sole of the foot is shown in *E*


A
B
C
6
7
8
7
S1
5
5 L

## *Sacrospinalis Muscle*

The sacrospinalis muscle is a large, muscular and tendinous structure which fills the gutter lateral to the spinous processes of the vertebral column. Inferiorly it is attached to the spinous processes of the 11th and 12th dorsal, all of the lumbar vertebrae, and the middle crest of the sacrum and the iliac crest. In the upper lumbar region these muscular and tendinous structures divide into three portions: the iliocostalis, which is the most laterally placed, the longissimus, which is in an intermediate position, and the spinalis, which is in a medial position. These three columns of muscular and tendinous structures are found all the way up into the neck and the base of the skull. Depending upon their position in the body, they are called lumbar, dorsal or cervical, respectively. The longissimus and the spinalis, which begin in the dorsal area, are subdivided into the dorsal, cervical and cranial or capitis portions.

The iliocostalis lumborum inserts into the lower borders of the angles of the lower six or seven ribs. The iliocostalis dorsi arise from the lower six ribs and insert into the upper six ribs and the transverse process of the 7th cervical vertebra. The iliocostalis cervicis is attached inferiorly to the third to the sixth ribs and superiorly to the fourth to the sixth transverse processes of cervical vertebrae.

The longissimus dorsi arises from the transverse processes of the lumbar vertebrae and inserts into the transverse processes of the lower eight thoracic vertebrae. The longissimus cervicis arises from the upper four or five thoracic vertebral transverse processes and inserts into the transverse processes of the second to the sixth cervical vertebrae. The longissimus capitis is attached inferiorly to the transverse processes of the upper four or five thoracic vertebrae and superiorly to the posterior margin of the mastoid process.

The spinalis group of muscles arises from the spinous processes below and inserts into spinous processes of vertebrae above. The spinalis dorsi is inferiorly attached to the last two thoracic and upper two lumbar spinous processes and superiorly, it is attached to the spinous processes of the upper six to eight thoracic vertebrae The spinalis cervicis is attached inferiorly to the ligamentum nuchae and superiorly, to the spinous process of the second cervical and possibly also to the next two cervical spinous processes. The spinalis capitis is usually a part of the semispinalis capitis.

The semispinalis group may be divided into the dorsal part, the cervical part, and the cranial part. These muscles arise from transverse processes and insert into spinous processes. The semispinalis dorsi arises from the sixth to the tenth dorsal transverse processes and superiorly, it is attached to the lower two cervical and the upper four thoracic spinous processes. The semispinalis cervicis inferiorly is attached to the upper five or six thoracic transverse processes and superiorly, it is attached to the spinous processes of the axis and the following four cervical spinous processes. The semispinalis capitis or complexus is immediately under cover of the splenius and is attached inferiorly to the transverse processes of the upper six or seven thoracic vertebrae, and the seventh cervical vertebra, and superiorly, it is attached to the squama of the occipital bone between the superior and the inferior nuchal line

# Neurosurgical Procedures

## Spinal and Cisternal Puncture

In *a* and *c* the position of the patient for lumbar and cisternal puncture with the needle in place is shown. In *a* a lumbar puncture needle has been inserted between the 2nd and 3rd lumbar vertebrae and this in turn has been connected through a three-way stopcock with a spinal manometer. A twenty or eighteen gauge needle may be used. After introduction of the needle and the placing of the manometer in position the flexed head and extremities may be extended to a normal position. When the lumbar puncture is used for the introduction of pantopaque® it is important to have the end of the needle almost touching the anterior dural lining. With practice this may be done without difficulty and without damage to the caudal roots or canal. For the usual lumbar puncture the interspace between the second and third spinous processes is satisfactory. For lumbar puncture associated with a myelographic study the interspace between the third and fourth spinous processes may be preferable. Occasionally the needle may be in the spinal canal and the subarachnoid space without escape of spinal fluid. This may be due either to a flap of arachnoid membrane over the end of the needle or to a very low pressure in the subarachnoid space. Both of these are easily remediable. In case of obstruction to the flow of fluid, if a 2 cc. syringe is used to clear the lumen of the needle by injecting a ¼ cc. of air, fluid will be forthcoming. In case of no pressure or very low pressure in the subarachnoid space, compression of the neck veins or straining on the part of the patient may cause the spinal fluid to flow from the needle.

In the study of the patient for a spinal block the neck veins are compressed on one and both sides, either manually or by the use of a blood pressure cuff applied about the neck. The pressure in the cuff is progressively elevated to 20, 40 and 60 mm. Hg held for 10 seconds and released. A notation is made of the rate of rise in pressure. Although at times a false block may be demonstrated on jugular compression, by moving the head anteriorly and posteriorly, a position may be found favorable for the accurate evaluation of conditions. If the fluid is xanthochromic the possibility of stasis or old hemorrhage must be considered. An adequate (5–10 cc.) specimen of spinal fluid is always sent to the laboratory and a cell count, albumin, globulin and total protein, as well as chlorides and serology, are routinely determined.



In *b* the position of the needle in relation to the lumbar spinous processes and the subarachnoid space of the spine is shown diagrammatically. The 1 mm. bore Ayer water manometer is used for determining spinal fluid pressure. Occasionally a patient with a pressure higher than 650 mm of water is encountered. In this instance the needle is immediately removed, the fluid in the manometer being used for a specimen.

In *c* and *d* the position of the needle for cisternal puncture is shown. A cisternal puncture is performed by introducing a No. 20 or 18 gauge spinal needle into the cisterna magna through the space between the occipital border of the foramen magnum and the posterior arch of the first cervical vertebra. The head is flexed with the patient either in a lateral or upright position. The position of the 2nd cervical spinous process is noted and in the thin individual the first cervical vertebra may also be felt just above the spinous process of the second cervical. After anesthetizing the skin the needle is inserted in the direction of the foramen magnum and if the occipital bone is reached the course of the needle is changed a little more caudad until the space between the border of the occipital bone and the first cervical vertebra is entered. This part of the maneuver is usually felt by the operator and the further progress through this region should be frequently checked by removing the stylet of the needle to see whether or not the arachnoid membrane has been entered. At times the cerebrospinal fluid may not escape, even though the end of the needle may be in the subarachnoid space. The use of a 2 cc. syringe for aspiration of cerebrospinal fluid or compression of the neck veins will establish this point. Spinal fluid may also be obtained if the patient takes a deep breath and bears down while holding the breath.

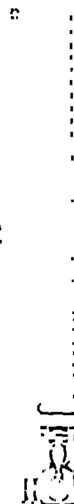
If a myelogram by the cisternal route is required 5 cc. of pantopaque® is injected into the cisternal subarachnoid space after having removed about 10 cc. of spinal fluid. The patient's head is tilted upward so as to keep the material from going into the fourth ventricle after removal of the needle. He may be placed upon the table prone or supine. A cisternal puncture is often simpler than a lumbar puncture. However, the possibility of damage to the upper cervical spinal cord or medulla exists.

The encephalogram is most easily performed with the patient in a chair designed for this purpose, allowing the head to rest comfortably in a flexed position When a lumbar puncture is done for the purpose of air encephalography the spinal fluid pressure should be measured. A rise of fluid above 450 mm. of pressure in lateral position is a warning that the procedure may be dangerous By the substitution method air or oxygen is introduced into the spinal subarachnoid space. At the completion of this procedure conventional roentgen studies are obtained both in the upright and horizontal positions.

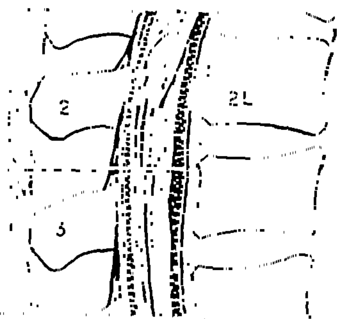
Occasionally a combined myelogram and encephalogram may be desirable The myelogram is done first and after removing the contrast medium the patient is placed upright and air is injected by the usual fractional method.


a


c




d


2
2 L
3



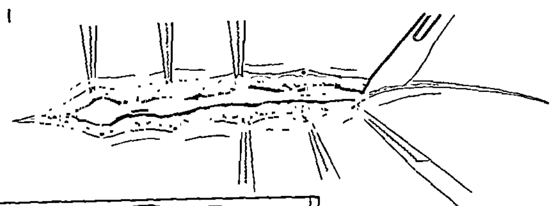
A laminectomy may be indicated for tumors within the spinal cord or canal, for chordotomy, rhizotomy or the treatment of traumatic lesions.

The more exactly the site of a lesion is known the smaller the laminectomy required; thus accurate localization is essential. In order to insure this during myelography the position of a defect may be indicated by a scratch of the skin with a sterile needle. This may only indicate the lower border of the lesion, if a lumbar myelogram has been done and the oil permitted to flow upward to the obstruction. The visualization of the upper end of the defect by downward flow of pantopaque injected in the cisterna magna may be desirable. The presence of multiple lesions may also be excluded.

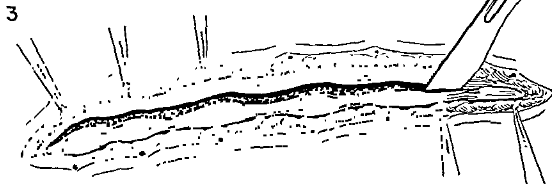
In patients with closed wounds of the spine the area of damage may be ascertained by roentgen studies and by the neurologic findings. In cases where operation upon the spinal cord or the roots is contemplated a knowledge of the relationship of the dermatomes to the spine and the spinous processes is important.

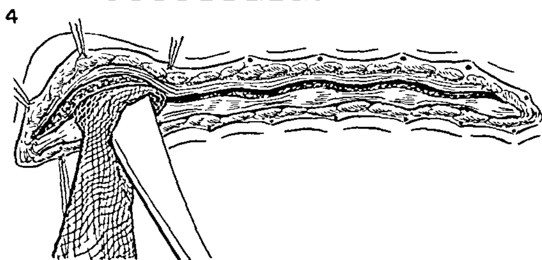
A rather extensive laminectomy is presented in the next three plates. To expose the spine from the second to the sixth dorsal vertebra a midline incision is made extending from the first to the seventh dorsal spinous process. The contemplated incision may be scratched out on the skin first with cross scratches in order to facilitate closure (*1* and *2*). After the application of hemostats to stop bleeding from the skin incision other bleeding points are now sought and coagulated with the electrocoagulating unit. In the obese patient the incision is extended down to the lumbodorsal fascia or the nuchal fascia in the cervical region so that the spinous processes can easily be palpated. The skin edges are retracted with self-retaining retractors designed for this purpose.

Immediately lateral to the spinous processes the lumbodorsal fascia is incised on either side of the midline *3*. Bleeding points from arterial and venous channels in this region are coagulated. These are the terminal branches of the dorsal branch of the intercostal vessels. The muscles attached to the spinous processes and laminae are carefully separated from the bones by blunt dissection of muscle insertions with a periosteal elevator aided by a piece of gauze preceding it (*4*). These muscles are the muscular and tendinous attachments of the spinalis, multifidus and interspinous groups. Several bleeding points may be encountered as the muscle is reflected from the spinous processes and laminae. These are coagulated. As the dissection proceeds, larger vessels, the dorsal branch of the intercostal arteries may be encountered between the contiguous vertebrae near the transverse processes. These are grasped with a bayonet forceps and coagulated with the electrocautery unit. The muscle reflection is carried out bilaterally. The muscles are stripped laterally to the articulating portions of the transverse processes. In *4* the method of scraping the muscle attachments off the bone is shown. This is accomplished using a chisel or a periosteal elevator, aided by a piece of gauze. When one side is completed several pieces of gauze are packed into this area, and the other side is exposed. Hot, wet gauze may be used thus aiding in hemostasis. The muscles are now separated with the use of two sets of self-retaining retractors placed above and below.


1


2


3


4

In *5* self-retaining retractors are used to hold the muscles away from the vertebral column. The interspinous ligaments are now cut with a knife or scissors. The spinous processes are now excised down to the laminae as shown in *6*. Using a double acting rongeur these may be removed with ease. In the lumbar area the spinous processes are much thicker and it may be necessary to use a single acting rongeur to grasp the processes for cutting. Bleeding from the bone is controlled with bone wax

As much of the spinous process is removed as possible. In between the laminae of consecutive vertebrae one sees portions of the ligamenta flava. A space between consecutive laminae is entered with a goose-neck double-acting rongeur and removal of the laminae is begun.

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*The Lateral Spinal Arteries*

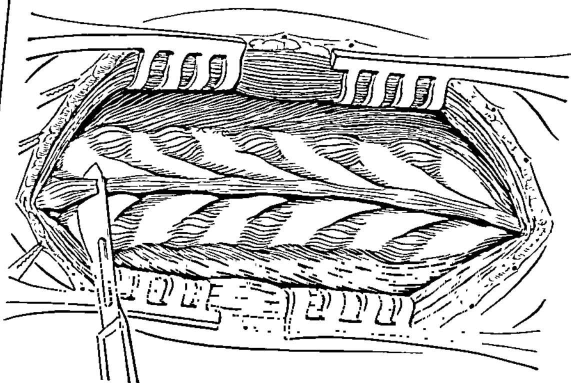
The lateral spinal arteries arise from the vertebral in the cervical region, the intercostal arteries in the thoracic area, the lumbar arteries in the lumbar region, and the sacral arteries in the sacral area. These vessels enter the spinal canal through the intervertebral foramina. They divide into anterior and posterior branches which accompany the anterior and posterior roots respectively. The one accompanying the anterior root extends to the anterior fissure whereas that accompanying the posterior root ends at the posterolateral sulcus of the spinal cord

Accompanying the anterior roots there may be from three to ten branches. The larger artery of Adankewicz accompanies the 10th or 11th dorsal anterior root and is much larger than the other arteries in the anterior roots

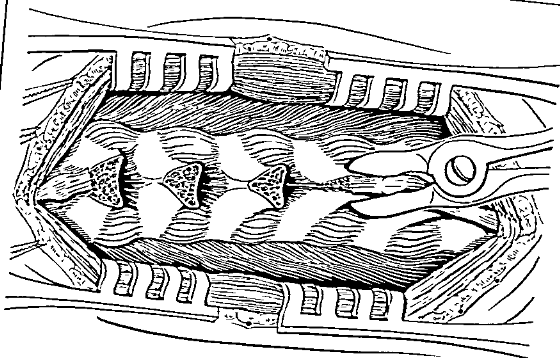
Branches accompanying the posterior roots are somewhat more numerous, usually there are about two such vessels for every three posterior roots There are between fifteen and twenty for the entire spinal cord. They are much smaller and thinner than those accompanying the anterior roots

In doing a rhizotomy these vessels are encountered. Bleeding can be controlled by the use of silver clips before section

5



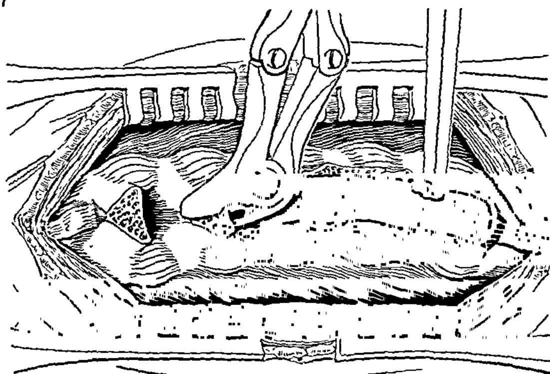
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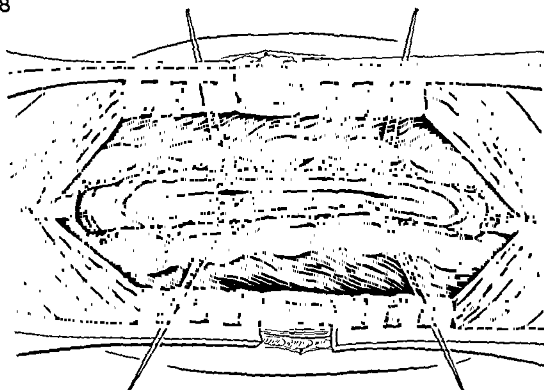


In *7* the use of two instruments is shown: a goose-neck rongeur for removal of the lamina and the Kerrison biting rongeur for enlarging the opening laterally. By inserting the Kerrison under the shelf of bone forming the lateral boundary of the spinal canal and removing the bone, a better lateral exposure is obtained. The lower blade of the Kerrison rongeur may be ground down so that it projects but several millimeters into the canal. The possibility of injury to the spinal membranes and cord is lessened, particularly in the presence of a tumor. As the laminae and intervening ligamenta flavae are removed, profuse bleeding may be encountered in the epidural space from veins which in some cases are plentiful. These veins should be carefully grasped with a bayonet forceps and coagulated. In some cases they may be ligated with silk. There may also be bone bleeding which may be controlled with Horsley's wax. After the laminectomy has been completed, if the peridural fat is still intact, it is incised, retracted laterally, exposing the dural sac. Cottonoid is placed about the muscle surface covering all but the exposed dura.

As shown in *8* the dural sac is now opened after placing one or two pairs of retraction sutures on either side of the proposed line of incision. After incision the dura is retracted with additional stitches extending from the cut border to the outside of the wound and held in place with hanging hemostats. In certain cases it is difficult to open the dura because of an underlying lesion. The dural incision, under these circumstances, must be begun below or above the lesion, until a normal line of cleavage is noted.

An extramedullary neurinoma is common. This may be dissected from the adjacent nerve roots of the spinal cord. A nerve root or a portion of a root may extend into the tumor mass. If so, this is cut rather than dissected. The tumor mass may be elevated by passing a suture through its substance for gentle traction as the dissection proceeds. With a piece of cottonoid at the end of a bayonet forceps the tumor may be carefully dislocated from its position, always directing the dissection away from the spinal cord rather than toward it. Traction or pressure should not be made against the spinal cord At times only a small degree of pressure may be sufficient to cause irremediable damage. Occasionally blood vessels extend into the tumor mass. If so they are carefully separated from the surrounding tissues, clipped and cut. The dentate ligament may be cut to make more exposure available in some cases. A neurinoma is usually easily separable from the surrounding tissues, except for the presence of one or more nerves extending into the tumor mass. The tumor can be elevated with successive sutures passing through its substance for gentle traction as the dissection proceeds. Occasionally the mass may be so large that removal by piece-meal excision may facilitate the eventual dislocation of the remaining mass. This method may be the only way to remove a tumor growing on the anterior aspect of the cord. The importance of gentle handling of tissues and tumor cannot be overemphasized in order to preserve spinal cord function.


7

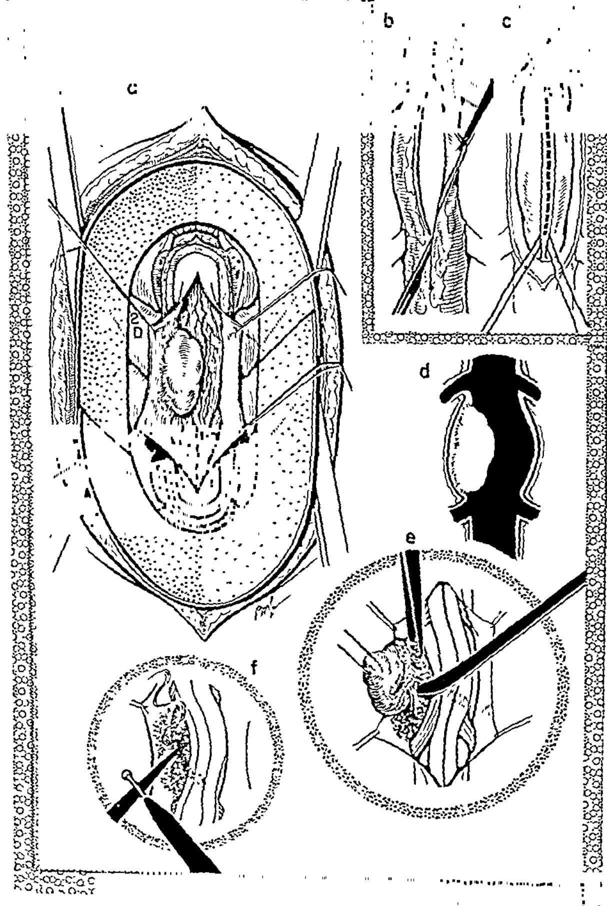

8

## Extramedullary, intradural meningioma attached to the dura ▶

After laminectomy the position of this tumor and the dural incision are shown in *a*, *b* and *c*. In *d* the silhouette of the tumor and its pressure against the spinal cord are shown. Such a tumor can be palpated with the index finger gently applied over the dura. After removing the epidural fat and fixing the dura with two pairs of stitches, the dura may be incised as shown in *b*. The tumor may involve the dura. It is best to excise that portion of the dura and cauterize the area peripheral to the region of involvement with electrocautery while protecting the spinal cord. In other instances it may be found that one is dealing with an invasive type of tumor. In these cases, the mass on the intradural aspect is only a portion of a larger one which extends into the extradural area of the canal. In this circumstance both the intradural and extradural portions are removed and the dura in this area is sacrificed. The defect in the dura is repaired with a lumbodorsal fascia transplant as shown on page 293. The dissection must avoid injury to the spinal cord, in removing such a tumor as shown in the accompanying illustration. Any vessels or nerves extending into the tumor are clipped and cut. The tumor is elevated from its bed, if necessary, by sharp dissection with scissors as shown in *e* After it is completely excised the area of attachment of the tumor is cauterized with electrocautery, *f*, with careful protection of the cord. Finally a test for patency of the spinal subarachnoid space is made by compressing the neck veins and observing under direct vision the unobstructed flow of the cerebrospinal fluid through the area of the exposed spinal cord. Hemostasis having been completed the dura is closed with a continuous lockstitch silk suture. Epidural bleeding, after dural closure is completed, may be controlled with gelfoam® or macerated muscle tissue. Any bleeding points in the muscle are coagulated; the muscles are approximated in two or three layers with interrupted catgut sutures. The lumbodorsal fascia is also approximated with silk or catgut sutures, followed by closure of the skin in layers with silk.

Drainage is not usual in such cases. Meticulous closure with complete hemostasis is essential.

After surgical removal the intradural but extramedullary lesions have been followed by spectacular results The common lesions are those of the meningioma group and the tumors of neural sheath origin or the neurofibromas, or neurinomas In the early history of spinal cord surgery the meningiomas and neurofibromas were frequently confused with each other Adson in 1925 reported an incidence of approximately two meningiomas to one neurofibroma, while it has been stated that the spinal meningioma is approximately one-third as common as the intracrani ningioma. The classification of spinal meningiomas is essentially the at for the intracranial group and these lesions, although smaller, h he same appearance They are usually slow-growing, but becau space relationships symptoms occur early and tragic deficits dev treated neoplasm which transects the spinal cord by its growth pointed out tha


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f

when the meningioma is adherent to the dura the dural attachment must be removed completely along with the tumor. It is possible, as pointed out by Cushing[16], "to utilize the adherent dura to draw upon the attached tumor as one may draw a patient to the side of his bed by pulling on the sheet beneath him". The neurofibroma or neurinoma does not infiltrate the dura and thus there is no prospect of recurrence after enucleation. The neurinoma is also "larger, smoother, softer, more elongated, and less likely to crowd its way ventral to the cord". Often a nerve root is present within the tumor mass and section of the root is involved in the excision of the tumor. The spinal fluid has been noted to have a more highly elevated total protein with the neurinoma than with any other tumor. This tumor also may develop in a dumbbell shape mass, growing through the intervertebral foramen and thus enlarging both inside and outside the spinal canal. Such a lesion most commonly occurs in the upper cervical region and has been stated to arise from the posterior root ganglion in the intervertebral canal. Occasionally intradural tumors have been noted to project through the foramen magnum thus producing a craniospinal syndrome.

Other extramedullary intradural tumors include vascular abnormalities, epidermoid, dermoid and teratomatous tumors. The dermoid tumors occur usually in the cauda equina. Implants from a medulloblastoma, involving the cerebellum, may also be observed in late stages.

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*Anterior Rhizotomy*

Anterior rhizotomy for the relief of mass rigidity and spasticity of the lower limbs, following spinal cord injury, has been described by Munro[49], Botterell, Jousse, Aberhart and Cluff; others have also used this method for producing flaccid paralysis in the lower extremities. A section of the lumbar nerves and the first sacral nerve has been satisfactory. The importance of saving the sacral preganglionic fibers to the bladder has made the procedure somewhat difficult. However, by the use of electrostimulation the sacral nerves involved in bladder function are not sectioned.

*The Spinal Arachnoid*

The spinal arachnoid is a thin membrane covering the spinal cord. It is traversed by many connective tissue bands and these are more numerous posteriorly. Pial vessels may be encountered in close vicinity of these bands and in exposure of the spinal cord, care must be taken to separate them from the dural lining. The arachnoid membrane surrounds the subarachnoid cavity which contains spinal fluid. A large quantity of spinal fluid is collected in the so-called lumbosacral cistern bathing the cauda equina.

## *Extradural Tumors*

The extradural tumors have their origin in the vertebrae; occasionally, the epidural fat, the blood vessels or the nerve roots. The commonest lesion is the metastatic tumor which may have its origin frequently in the lung, breast or prostate. Pain, due to nerve root involvement, often first serves to identify the lesion. Subsequent growth results in profound neurological disability; the final result often being a paraplegia. The advisability of surgical treatment by decompression has been raised in the management of this type of lesion. We have felt that the effort should be made to spare power, sensation and bladder function for as long a period of time as possible. This aids not only the comfort of the patient and his morale, but it assists in nursing care.

Other extradural lesions encountered are the myelomas, frequently involving the upper thoracic and lower cervical portions of the spine. These usually respond for several years to removal followed by roentgen therapy. Chordomas may be encountered particularly in the region of the sacrum, producing nerve root signs without involvement of bone. In the early period of growth this may result in a confusing clinical picture. In early stages the myelographic studies may be entirely normal. Lipomas, sarcomas, and the hourglass tumors described by Heuer, may be encountered as well as vascular lesions such as the hemangioma involving bone and soft tissues. Extradural granulomas also deserve mention, since the same indications for decompression of the spinal cord are found in the presence of an obstructing or compressing lesion.

Dumbbell tumors are hourglass lesions, usually with the smaller portion in the spinal canal or dural sac, and the larger mass in an extraspinal position. These parts communicate through an intervertebral foramen or the space between the laminae. In the presence of such a tumor, excision of the spinal portion first is advisable. Roentgenograms and myelography usually clinch the diagnosis.

## *Epidural, Subdural and Spinal Cord Abscess*

Spinal epidural abscess is usually a fulminating disease with an onset of severe root pains followed by progressive neurologic deficit resulting in paraplegia. Early recognition and laminectomy may save or restore function.

The level of an epidural abscess may be indicated by an exquisitely tender site, especially early in the disease. A myelogram is advisable to confirm the clinical findings. At operation the abscess is adequately exposed, cultured, removed and irrigated. An associated soft tissue collection may be present communicating with the epidural space. The wound is closed tightly about a small catheter into which penicillin solution (50,000 units) is instilled at closure and for several days postoperatively.

Rarely, an intradural abscess may be encountered. In this instance the dura is opened; the single or the multiple purulent areas accompanied by adhesive inflammatory arachnoiditic changes are drained and irrigated. The dura is closed about a tiny pliable catheter led out through the wound for antibiotic instillation.

*(Continued on page 264.)*

Many of these tumors are malignant, invasive lesions and frequently of metastatic origin. The upper dorsal area is a common location. In *b* the laminectomy has been performed. The presenting tumor is shown. The use of the Kerrison rongeur in tumors of this type is helpful since a lateral exposure is needed to view the tumor extension. The laminectomy is extended superiorly or inferiorly as necessary to expose both the superior and inferior portions of the tumor. In this particular instance two nerves were invaded by the tumor as shown in *a*. The tumor was elevated from the dura with scissors and cottonoid dissection, *c*. As shown in *d* the tumor tissue extended from the lateral aspect of the spinal dura toward the anterior aspect of the spinal canal, and though roentgen studies may not show invasion of bone, at operation, both lateral processes, as well as portions of the body of the vertebrae, may be involved by tumor tissue. As much as possible is removed with a pituitary forceps until the dural sac is decompressed. In this particular case it was advisable to section the posterior portion of the involved roots to relieve pain from tumor involvement. In *e, f, g* and *h* is shown the sequence of a rhizotomy. In *e* the dura is opened after placing retraction sutures. At *f* the posterior roots have been isolated; grasped with a hook and cut with a scissors. Bleeding points may be controlled with silver clips. The anterior roots need not be cut. After complete hemostasis the dura is closed with a continuous lockstitch and the wound closed in layers as described before.

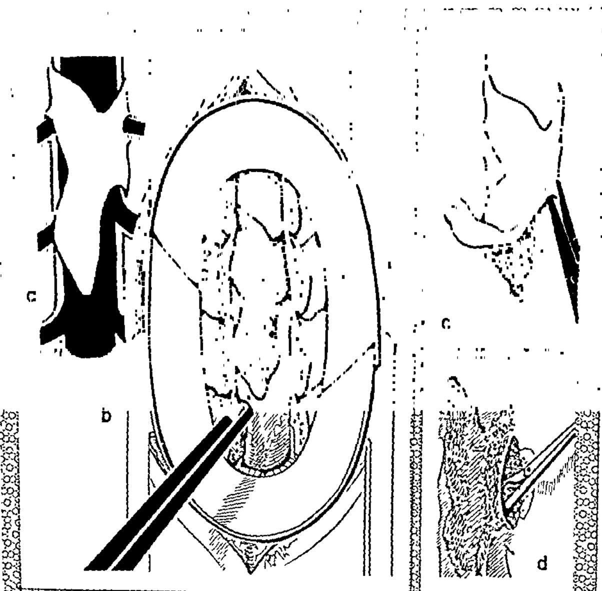
Following the removal of a tumor of this type, pulsations of the spinal dura which were not present previously, become visible again as the pressure is removed.

A number of these extradural masses in the upper dorsal area are solitary myelomas. Excision of such a lesion permits complete recovery of a patient who may be almost completely incapacitated. He may remain well for a year and a half to two and a half years. Thereafter, secondary operations provide small benefit.

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*Epidural, Subdural and Spinal Cord Abscess (concluded)*

Abscess of the spinal cord is also very rare. A bulging, fluctuant cord should be tapped with a 20-gauge needle attached to a syringe. If pus is obtained, the cord should be incised supero-inferiorly, just lateral to the midline in an avascular region. The cavity of the abscess is washed out with penicillin—dura is left open with an inlying ureteral catheter for injection of penicillin for several days after operation.


a
b
c
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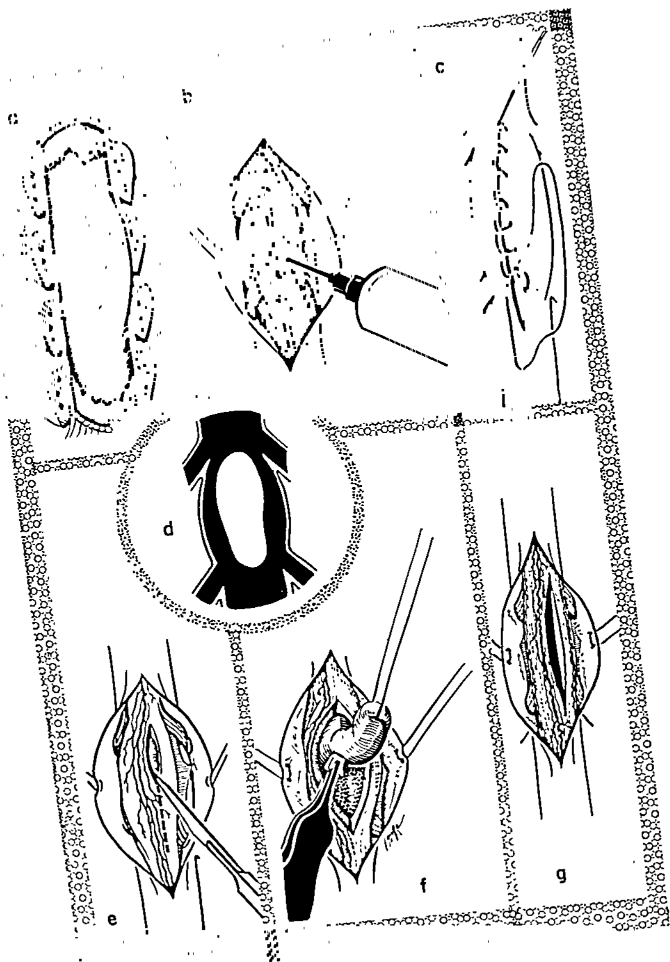
# Intradural intramedullary tumors and their management

*The results in the surgical* treatment of *intradural, intramedullary* tumors are usually quite unsatisfactory. Two types of lesions are noted; *viz.*, a soft, infiltrating tumor with some areas of liquefaction and necrosis, resulting in cystic cavities; and the solid tumor, which may be removed through an incision in the spinal cord and gentle dissection. These intramedullary tumors have a typical myelographic delineation.

In *a*, after laminectomy, an intradural, intramedullary tumor is shown causing a localized bulging of the dural sac. In *b* the dura has been opened. *The lateral and anterolateral surfaces* of the cord are inspected in order to insure that the lesion is intramedullary. The mass is now explored with a 20-gauge needle passed into the spinal cord. A soft mass may be entered or the resistance of a hard mass may be felt. A cystic area may be entered. With gentle traction upon the plunger of the syringe, yellow fluid may be removed. If a cyst is small or absent in a soft mass, one is dealing with an infiltrating tumor of the spinal cord, most probably an ependymoma. Under these circumstances no further manipulation is advisable. On opening the *dura, marked bulging of the cord makes closure difficult and it may be left* widely opened. The dura is closed if such can be accomplished without tension. The dentate ligaments may also be sectioned at the site of the cord swelling, if this be easily permitted. Remarkable improvement occurs in some cases. The improvement may last over a long period of time, a matter of fifteen or twenty years or even longer. In *d* the position of a tumor is diagrammatically presented. At times a portion of such a tumor may present *itself on the surface of the spinal cord, simulating an extramedullary lesion,* but as dissection proceeds it is evident that this is in fact an intramedullary lesion. Deep irradiation therapy is used postoperatively in treatment.

A solid tumor within the substance of the spinal cord can be felt with the *exploring needle. Through an incision in the paramedian avascular dorsal* surface of the spinal cord, the tumor is exposed through its entire length. Good exposure will facilitate the removal with as little damage to the spinal cord as possible. The lower or the upper end of the tumor, whichever is easier, is enucleated from the surrounding spinal cord by traction upon the tumor provided by a stitch passed through its substance. Should the tumor uniformly invade the spinal cord, only a biopsy should be obtained. In some cases complete removal is impossible as the tumor tissue becomes imperceptibly continuous with the cord substance In *e* the incision in the paramedian position is shown At *f* the tumor is being carefully separated from the surrounding spinal cord In *g* the incision and the cavity of the tumor are shown

Gowers had stated that "these tumors in some cases blend with the substance of the cord, but in others they are bounded by an area of softening *which often isolates even invading growths. Such tumors* are sharply limited.


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The removal of such a tumor could hardly fail to cause a traumatic inflammation that would damage and perhaps destroy all the elements of the cord at the spot, and would probably be permanent in its effects".

The wide experience of Elsberg led him to adopt a less conservative policy. He described what he termed a technique for the "extrusion of intramedullary tumors". Upon identification of a localized neoplasm, of intramedullary type, an incision was made overlying the lesion through a thinned avascular area in the posterior column. The wound was then closed and this was considered the first stage of a two-stage procedure. The second stage was then performed for removal of the extruded neoplasm, if indicated.

Experience has taught however that conservatism is by and large the most satisfactory policy in dealing with the intramedullary lesion. Incisions into the spinal cord can be made only at great risk. This risk cannot be taken unless an enucleable lesion can be positively identified. Only then is an overlying longitudinal incision warranted. An evaluation of the intramedullary lesion should be made by means of an exploratory No. 20 gauge needle attached to a syringe. This will identify a cyst, a solid tumor, and at times, provide bits of tissue for microscopic examination. The judgment which determines the advisability of cord incision must be influenced by the patient's neurological status at the time of operation.

## Surgery of Ruptured and Protruded Intervertebral Discs

### Historical Considerations

Although rupture or protrusion of the intervertebral disc may occur at any level of the spinal column, the majority are found in the lower lumbar area The lower cervical region is the next area in frequency of involvement. The presence of a ruptured disc has been recognized in the operating room for many years. The lesion has been called by other names, such as chondroma, achondrosis, fibrochondroma, etc. Almost always the early lesions were not suspected before operation, the patient having undergone the exploration for a cord tumor. In the next few paragraphs certain points in the development of the knowledge pertaining to ruptured discs will be discussed under the headings of lumbar and cervical protrusions and ruptures.

### Ruptured Lumbar Discs

In the early part of the present century the occurrence of both pain and paralysis in the lower extremities, resulting from benign extrusions into the lumbar sac, was recognized. In 1909, Oppenheim and Krause reported a case of "strangulation of the cauda equina" caused by "an enchondroma of the posterior surface of the body at the third lumbar vertebra which had considerably narrowed the vertebral canal". Operation was performed in 1908 with a cure of the patient The cauda equina was exposed by a laminectomy

and "after the cauda equina was lifted upward with a pair of blunt hooks, the tumor, twice the size of a bean of longitudinal direction, situated in the lower portion of the wound, came into view. It was covered by normal dura from the posterior surface of the body of the vertebra. The neoplasm was of solid consistency. A longitudinal incision was therefore made into the anterior surface of the dura above the highest level of the tumor and the latter was removed as radically as possible by means of a sharp spoon". Microscopic examination of the tumor showed it to be "mainly of cartilage tissue with few cartilage cells. The fibrous elements were fairly strong and blood vessels extremely few".

Others encountered similar lesions, describing them as chondroma or enchondroma. Elsberg[23], in 1915, referred to a patient operated upon and "a ruptured ligamentum subflavum was found to have compressed the fourth lumbar root and with the excision of the ligament the pain disappeared". A fundamental early clinical contribution was made by Goldthwaite concerning the "lumbosacral articulation and explanation of many cases of lumbago, sciatica, and paraplegia". Goldthwaite described in detail his experiences involving a patient who had suffered pain as a result of leaning forward and straining to get out of a tub. The pain was present in both lower extremities; greatest on the right with tenderness in the sacral region. Believing the lesion to be a sacro-iliac displacement, an attempt was made first to manipulate this joint. This being unsuccessful, on the same day an attempt was made to place the patient in hyperextension in a plaster of Paris jacket. "As the patient was placed in position there was a moment of intense pain followed by complete relaxation". This was followed by a loss of sensation in both lower extremities and sphincteric paralysis. Upon being placed in bed, however, the neurological deficits improved, to return when the patient remained on his back and finally becoming permanent by the next morning. At the end of six weeks, since the patient had not improved, he was explored by Cushing. The spinous processes and laminae were removed from the first lumbar vertebra to the middle of the sacral region and nothing abnormal was found except narrowing of the osseous canal at the lumbosacral junction. "The cauda equina appeared normal. There was no evidence of hemorrhage and no evidence of new growth". Goldthwaite then reasoned on a clinical basis that one could exclude the possibility of the cauda equina having been torn or crushed; that hemorrhage, a tumor in the spinal cord, and disease of the vertebral bones also could be eliminated. He stated, "Another element which was not at first appreciated, which is undoubtedly of much importance as a direct cause of the paralysis, consists in the formation and possible displacement of the intervertebral disc lying between the body of the vertebra and the sacrum. This structure, as is peculiar to the same structure in the rest of the spine, is made of two parts; one, the peripheral or outer portion, called the annulus fibrosus, the other, the central portion called the nucleus pulposus".

By exhaustive and thoughtful study of a *single* case, Goldthwaite was able to make these sound observations.

It required the laboratory studies of Schmorl[57, 58, 59] in 1929 to correlate the etiology and mechanism for strangulation of the cauda equina or of a root by a pathological and mechanical disturbance within the intervertebral disc. After removing and sectioning in a sagittal plane the vertebral columns in routine postmortem examination, he found that a prolapse of the nucleus pulposus occurred into the adjacent vertebral body in thirty-eight per cent of the spines examined. He termed these intrusions into the body "cartilage nodes or Knorpel Knotchens". Schmorl noted about fifteen per cent of small posterior prolapses beneath the posterior and longitudinal ligament which he attributed to degenerative changes in the annulus fibrosus, associated with trauma

The syndrome of the ruptured lumbar disc gradually gained recognition. Dandy, in 1929, reported on "loose cartilaginous discs simulating tumor of the spinal cord". In the two cases reported the spinal canal was completely blocked as shown by the use of iodized oil prior to operation. The lesion was described as "a completely detached fragment of cartilage from an intervertebral lumbar disc. It bulges dorsally into the spinal canal as a tumor and by compressing the roots of the cauda equina, causes motor and sensory paralysis, loss of reflexes and of rectal and vesical control. The lesion is undoubtedly of traumatic origin". He stated also the fact that the two cases appeared only a few months apart, "leads me to believe that the lesion may not be so infrequent". This observation was later, in 1934, confirmed by Mixter and Barr who reported on "rupture of the intervertebral disc with involvement of the spinal canal". These observers not only confirmed that "herniation of the nucleus pulposus into the spinal canal, or as we prefer to call it, rupture of the intervertebral disc, is not an uncommon cause for symptoms" but they also emphasized that root symptoms and signs alone were possible due to compression at the intervertebral foramen. A monograph upon the subject appeared by Mauric in 1933 and was referred to by Mixter and Barr.

Within the following decade the frequency of herniation of the nucleus pulposus as a cause for clinical symptoms and disability was established. The transdural operations through a laminectomy were replaced by means of extradural operations with minimal bone removal The diagnosis, although based mainly upon clinical symptomatology and signs, was aided by the use of contrast media, first lipiodol® and subsequently pantopaque,® the latter medium being removed at the end of the radiological procedure.

## Cervical Nucleus Pulposus

In 1928 Stookey described seven cases of neurologic disability caused by what was described as a ventral, extradural cervical chondroma. Three of these lesions exerted unilateral pressure on the ventral column of the spinal cord; three resulted in bilateral compression, with bilateral signs, and dorsal angulation of the cord, while one was situated more laterally, giving rise to nerve root signs only. Stookey advised surgical treatment for this lesion by means of a hemilaminectomy with a transdural approach and removal of the lesion This was subscribed to also by Elsberg[25] who emphasized that "the

growths are usually small and easily missed unless the dura is opened. They lie in the midline or more to one or the other side and a projection of the anterior dura can be seen when the cord is drawn to the side by traction on a divided slip of the dentate ligament". Elsberg also suggested that "those who make postmortem examinations should carefully examine the posterior surface of the bodies of the cervical vertebrae and intervertebral cartilage in all autopsies on the bony spine" toward a better understanding of this condition. This suggestion was at that time being carried out by Schmorl[57, 58, 59], who shortly reported in 1929 the pathophysiology of the nucleus pulposus. This resulted in the revised concept that the compressing mass was not a chondroma or neoplasm, but a protrusion of the nucleus pulposus through the annulus fibrosus. Subsequently, Semmes and Murphy emphasized that nerve root involvement was more common than the bilateral or unilateral cord compression. They pointed out the possibility that painful shoulder, chest and arm syndromes (suggesting angina pectoris), arthritis of the cervical spine, brachial plexus neuritis and neuralgias, bursitis and the cervical rib syndrome, may be instead the result of cervical nerve root compression involving the 6th, 7th or 8th nerve roots.

The most common locations for herniation of the cervical nucleus pulposus are at the 5th, 6th and 7th interspaces. Symptoms and signs include pain in the neck, with radiation into the upper limb, exaggerated when the head is flexed or when the head is thrust downward toward the thorax, with the head in a slightly flexed position. There may be some rigidity of the neck. With a 5th interspace involvment there is often loss of the biceps tendon reflex with pain along the lateral aspect of the shoulder, and forearm to the thumb, and possibly also the index finger. There also may be a feeling of numbness in the thumb and index finger on the affected side. With 6th interspace involvement the 7th cervical nerve is mainly compressed with pain in the shoulder, the medial aspect of the arm and forearm, extending into the long and ring finger neighborhood. There is usually a loss of the triceps tendon reflex. There may be some sensory loss in the long and ring fingers. In the 7th cervical interspace involvement there is compression of the 8th cervical nerve. The distribution of pain may involve the upper chest on the affected side, the medial aspect of the arm and forearm extending into the little and ring fingers. In many instances actual neurological deficits cannot be demonstrated. The type of pain, its distribution and duration may make it desirable to investigate such a case further by lumbar puncture with pantopaque® myelography.

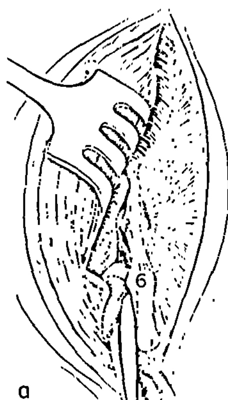
Usually, lumbar puncture reveals clear fluid with no evidence of block and but a slightly increased total protein. Pantopaque® myelography is frequently diagnostic. For this purpose 6 cc. of pantopaque® is injected into the spinal subarachnoid space at the 3rd or 4th lumbar interspace. The oil is permitted to enter the cervical area by tilting the table in such a manner that the oil is kept from going into the cranial cavity. This is accomplished by posterior flexion (hyperextension) of the head. A triangular area of defect in the vicinity of an outgoing nerve is usually the characteristic deformity in the myelogram.

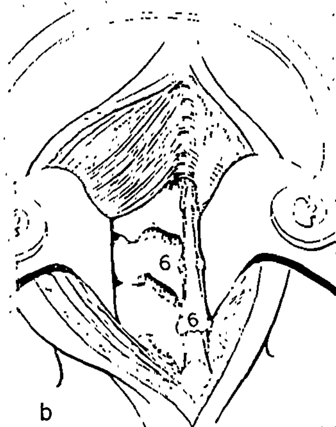
A hemilaminectomy for cervical disc can be done with the patient in a sitting or prone position. In the accompanying illustrations, the operation *was performed in the sitting position as shown in d. The incision over the* spinous processes of the 4th, 5th, 6th, 7th cervical to 1st dorsal vertebra is shown at *d1*. In *a*, after making an incision in the midline of the back of the neck and thorax, the ligamentum nuchae and the spinous processes of the lower cervical and 1st dorsal vertebrae are exposed. Usually the 6th spinous process and those above this level are terminated in a bifid process. The 7th cervical has a high globular termination (below *6* in *a*); so do the dorsal spinous processes. The ligamentum nuchae is incised on the side of the operation for the ruptured disc. In this instance it is on the left side. The spinous processes of the 7th cervical and the 1st dorsal are easily brought into view, but the bifid spinous process terminations of the 6th and the 5th *are more difficult to expose Cutting with scissors or a knife may be indi-*cated. Many large venous channels and arterial vessels may be encountered and these are coagulated with the electrocautery.

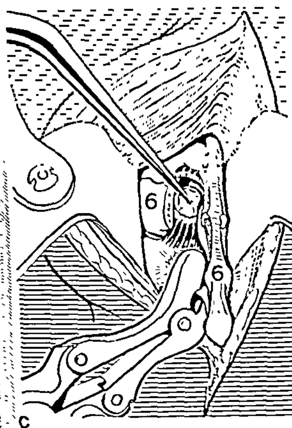
In *a* the technique of exposure of the spinous processes and laminae in the lower cervical area is shown. The ligamentum nuchae is incised on the side of the projected hemilaminectomy. The bifid portions of the spinous processes of the 5th and 6th are separated from the attached muscles on the left side. The muscles are also dissected away from the spinous processes and the laminae with gauze and periosteal elevator dissection. A deep self-retaining retractor may be used to retract the muscles. Other muscular and tendinous attachments may be cut to expose the laminae laterally to the transverse processes.

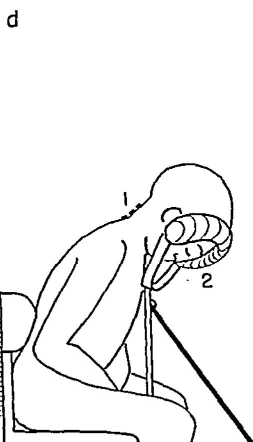
In *b* the 6th cervical vertebra to the left of the midline is shown. Self-retaining retractors are used to hold back the tissues. The laminae of the 5th and 7th cervical are also seen In *c* the lamina of the 6th cervical has already *been removed. The lamina of the 7th cervical is being removed.* The ligamentum flavum in the cervical region is thin but can always be demonstrated. A maximum lateral exposure is most important in this operation, and the use of a Kerrison rongeur with a flat-bottomed outer plate or blade is necessary. *The shelf of bone, on the lateral portion of the opening, may* thus be engaged with a Kerrison and bitten off for better exposure. Some surgeons prefer a dental drill to accomplish this. The ligamentum flavum in the cervical area is very thin and it usually comes off at the same time that the bone is being removed for the hemilaminectomy. It is important at all times to know the position and number of the lamina to be investigated. As shown in *b*, the spinous process of the 6th is in a position much lower than the lamina of the same vertebra.

When hemilaminectomy has been completed gentle palpation of the outgoing nerve reveals the presence of a mass underlying the nerve. In some cases the operator may desire to expose not only the involved interspace but also the interspace above and the interspace below.


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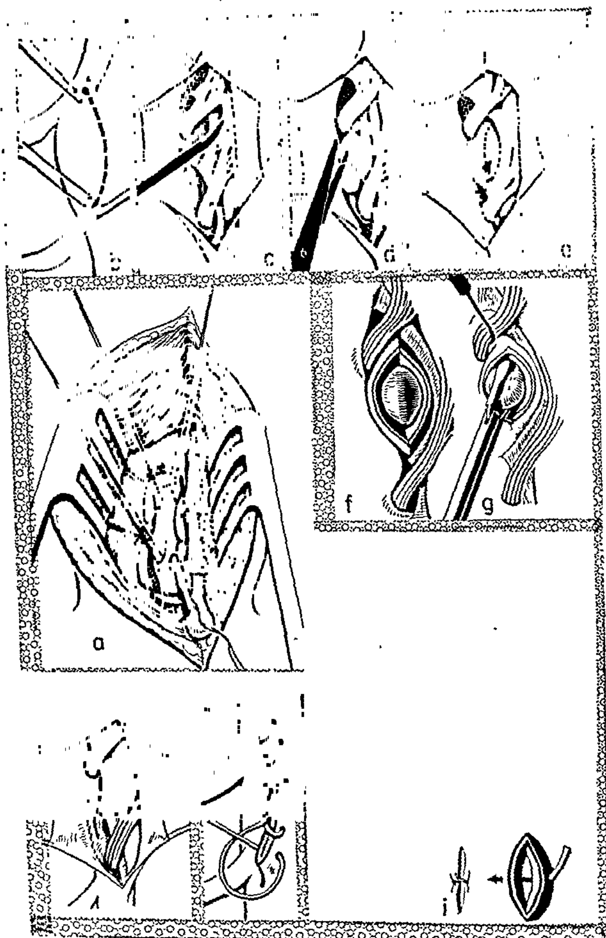

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When the hemilaminectomy has been completed the presence of a mass under the outgoing nerve may become quite evident on palpation. Such a mass may present immediately below the outgoing nerve and it may be seen as a soft, bulging translucent structure. If so it can be incised and the contents removed with a pituitary forceps. A small blunt nerve hook may be helpful in elevating the nerve root from the mass. Following removal the outgoing nerve is relaxed. This may be all that is needed. On the other hand, if the ruptured disc does not present itself as a bulbous mass extruded laterally either below or above the outgoing nerve and if the surgeon feels that there will be extensive manipulation of the outgoing nerve to reach the mass, then a transdural approach is safer.

On the accompanying page such an intradural approach is illustrated. At *a* the dura is shown transfixed with a pair of silk sutures about the projected incision. In *b* the position of the curved incision is shown. The dura is elevated with sutures and incised. At *c* the dura is retracted and the denticulate ligament is seen. At *d* the denticulate ligament is cut with a scissors or a pointed knife blade. As shown in *e* the ruptured portion of the disc comes into view. The position of the incision in the anterior dural lining is shown by the arrow. This incision permits the extrusion of the protruded disc as shown in *f* and *g*. Through the use of a pituitary forceps the extruded portion of the disc may be gently removed. The outgoing nerve root may be retracted upward or downward depending upon the ease with which it can be retracted. Ordinarily it is not necessary to retract the spinal cord but this can be done easily over cottonoid protection. Extreme care and gentleness is necessary to prevent spinal cord and root injury. In *i* the anterior dural opening is closed with a single interrupted silk suture. In *j* and *k* the dura is closed.

By the use of the intradural route not only a good exposure of the ruptured portion of the disc may be obtained but also section of the denticulate ligament may be done. This is of some help in avoiding traction injury of the spinal cord, or the outgoing nerve root.

There appears to be a value in a section of the dentate ligament, particularly in the solid type of disc which cannot be removed. In some cases, both the intradural and extradural removal of the disc may be preferable. We have found the intradural much more satisfactory in many cases. In patients with a solid disc traction for exposing the mass extradurally may injure the spinal cord and nerve roots with disastrous results. By intradural exposure retraction is controlled better.

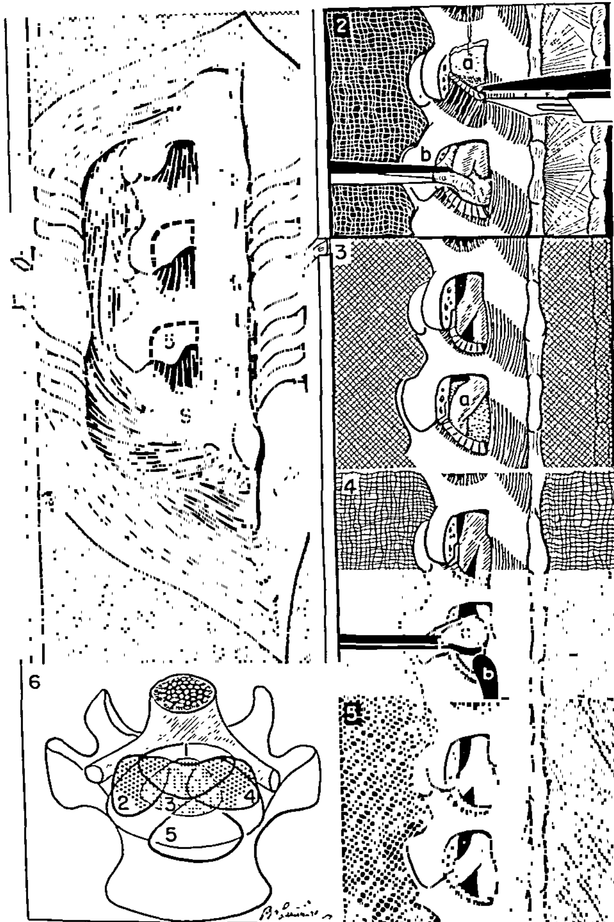

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Eighty per cent of lumbar ruptured discs occur in the lower lumbar area, at the 4th and 5th lumbar interspaces. Ruptured discs in this position are usually characterized by low back pain with radiation in the distribution of the sciatic nerve of one or the other side, or in some cases, on both sides. With 3rd interspace invólvement there may be a sensory deficit, located on the lateral aspect of the thigh and extending down and medially to the knee. With 4th interspace involvement the sensory loss extends all the way down to the lateral aspect of the leg, the dorsum of the foot and the big toe. With compression of the root at the 5th interspace there may be hypesthesia of the lateral two or three toes, the lateral aspect of the foot and the lateral aspect of the leg and thigh. Other characteristic findings include listing usually away from the side of the lesion; pain upon straight leg raising on the side of the sciatica; rigidity of the lower spine, particularly on bending forward or toward the side of the ruptured disc. There may be pain upon coughing or sneezing; pain upon the compression of the neck veins. The 3rd lumbar interspace lesions may be associated with a lost or reduced knee jerk; the 4th lumbar interspace extrusion may be associated with weak dorsi-extension of the toes, and in some instances, a foot drop may be present. In 5th lumbar interspace involvement there is usually a loss of the Achilles jerk.

Myelography is a worthwhile aid in diagnosis. Six cubic centimeters of pantopaque® is injected between the 2nd and 3rd or 3rd and 4th lumbar vertebrae. After completion of the procedure most of this pantopaque® is usually removable under fluoroscopic control. It should be pointed out that above the 5th lumbar level the pantopaque® myelogram is much more accurate than at the 5th lumbar level where there may be 15–25 per cent error including false positive or negative interpretations.

In *1*, through a midline incision in the lower back over the spinous processes of the 3rd, 4th and 5th lumbar and 1st sacral (S-1) vertebrae, the 4th and 5th lumbar and the 1st sacral spinous processes are exposed. The patient under intratracheal ether has been placed face down with the lumbar spine moderately flexed. The lumbodorsal fascia is incised just lateral to the spinous processes on the side where the partial hemilaminectomy is to be performed. Venous and arterial channels may be cut and these are coagulated. These are twigs of the terminal branches of the lumbar vessels. The medial terminal vessels are in a position lateral to the spinous processes. The muscles are separated from the spinous processes and laminae by dissecting against bone with a periosteal elevator, attempting to achieve a subperiosteal removal of the soft tissues. This reduces hemorrhage. The muscles encountered are the sacrospinalis and the multifidus. As the dissection is extended laterally some tendinous connections are sectioned with scissors or the knife.


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The laminae and the articular processes of the vertebrae are exposed. During this procedure bleeding points may be noted between consecutive pedicles for the arrest of which the coagulation current is used. These are the branches of the dorsal lumbar vessels. In *1* the 4th and 5th lumbar and 1st sacral laminae have been exposed. The interspaces can be seen after the muscular tissue (mostly multifidus) is removed. The ligamenta flava may be seen between these consecutive vertebrae. The area of the partial hemilaminectomy is outlined with the dotted line, on the 4th and 5th lumbar laminae on the left. The goose-neck rongeur is used to remove this portion of the lamina. At times the laminar border is too thick and a double acting rongeur cannot grasp the bone adequately. A single acting Taylor type of rongeur is used. The cutting blades of this type of rongeur open widely.

In 2 the hemilaminectomy has been performed at the 5th and 4th lumbar areas. The ligamentum flavum is grasped with a hook at the 4th interspace under which is passed cottonoid to protect the dura from injury, *2a*. With care the ligamentum flavum is excised by incision of its medial and caudal attachment, as well as its attachment to the lateral aspect of the vertebral canal. The ligamentum flavum is removed completely in its lateral attachment so as to avoid a shelf of ligamentous material obscuring the outgoing nerve. The lateral exposure in the bony canal may be obtained with the use of a Kerrison rongeur. This may be done after the Taylor type rongeur has been used. It is usually necessary to excise the bone-ligamentum flavum junction, at the lateral aspect of the hemilaminectomy. In such cases the articular processes crowd this region. A portion of these processes may be removed also.

When the ligamentum flavum has been removed from the 4th and 5th interspaces the presence of a ruptured disc may be detected by carefully inspecting and palpating the area with the tip of a blunt instrument such as the bayonet forceps The nerve root must be identified and retracted for this inspection One may decide at this point whether or not the exposure is satisfactory or whether it is preferable to extend the hemilaminectomy more inferiorly and laterally because of the position of the ruptured intervertebral disc. If the extrusion is in an inferior position and extends out under the outgoing 1st sacral nerve at the 5th lumbar interspace, then more exposure inferiorly and laterally is desirable. In *3* hemilaminectomies have been performed at the 5th and the 4th interspaces. The outgoing nerves are now visualized. At the level of the 5th interspace a large ruptured disc is seen which is compressing the out-going nerve. The 4th interspace appears to be clear from a posterior view. At *a*, with gentle retraction of the 1st sacral nerve medially, with a blunt periosteal elevator or a Love retractor, the ruptured disc is brought into view and if it has a lining sheath it is incised. In other instances the disc is already free in the epidural space and can be lifted as shown in *4a* with pituitary forceps. Usually, the material may come out in one or several large pieces. In other instances, piece-meal removal of

the ruptured disc may be necessary. If the disc is not apparent in a lateral position and if the myelograms are quite positive for the presence of a good sized lesion, one should not be satisfied with a small protrusion but should extend the exposure more medially, laterally and inferiorly. Eventually a large protruded mass is usually found and may be removed. In most instances, the outgoing root can be retracted medially. Occasionally, an extrusion may cause a lateral migration of the outgoing nerve so that its removal is made in the angle between the outgoing nerve and the dural sac. This is unusual but such a possibility should be kept in mind. Removal by this route is preferable to that of retracting the root, not easily mobilized medially. This may result in injury to the root by tension. In other instances, the disc may be found to be extremely adherent to the surrounding tissues. This is particularly true in those patients who have repeated attacks of sciatica with intervening remissions.

After completing the work at the 5th interspace and stopping all bleeding points, one may then go on to the 4th interspace. Bleeding may be stopped fairly efficiently by grasping bleeding veins and coagulating them with electrocautery, and wounds without active bleeding may be stopped by the use of gelfoam® which is placed in this region until it is time to close the wound. The material is then removed. At the 4th interspace the outgoing nerve is carefully retracted medially and the underlying tissues, including epidural veins, pushed away from the disc by means of small cottonoids. A mere bulge of the disc is not an indication for incision and removal of the nucleus pulposus. An enlarged, boggy, soft disc should be explored and in many instances, large sequestrated pieces of material are removed following incision of the annular ligament.

Frequently, after the ruptured disc is removed, a large opening is found extending into the interspace. Several fragments of material may be present in the interspace and these are removed with the use of pituitary rongeurs, either straight or angled. The dissection should avoid vigorous plunging of the forceps too far anteriorly into the disc, risking the possibility of injury to venous or arterial channels in front of the bodies of the vertebrae.

In *6* the possibilities for the various locations of the rupture of the intervertebral disc are shown. In the positions *2* and *4* there may be unilateral root pain. In position *1*, there may be bilateral root pains with complaints referable to both lower extremities. In positions *3* and *5*, backaches may predominate. In a massive extrusion of the midline lesion a cauda equina syndrome occurs. Lesions in positions *2* and *4* at times may extrude into the foramen. The necessity to explore the intervertebral foramen in all these cases cannot be over-emphasized.

## *The Pia Mater of the Spinal Canal*

The pia mater of the spinal canal is somewhat thicker than that in the cranial cavity. Roughly, it consists of two layers, between which blood vessels and perivascular lymphatic spaces are found. On either side of the spinal cord it gives off the ligamenta denticulata of which there are twenty-one pairs. At the termination of the spinal cord the pia mater is continued as the filum terminale internum, which extends downward in the cauda equina to the level of the second sacral vertebra, where the dural sac terminates. At this point the filum terminale internum becomes continuous with the dura, and thence extends as far as the base of the coccyx, as the filum terminale externum and blends with the periosteal lining of that bone. The denticulate ligaments and the filum terminale help hold the spinal cord in position during movements of the body. The pia mater extends out with spinal nerves, becomes continuous with the connective tissue lining of these nerves.

## *Torticollis*

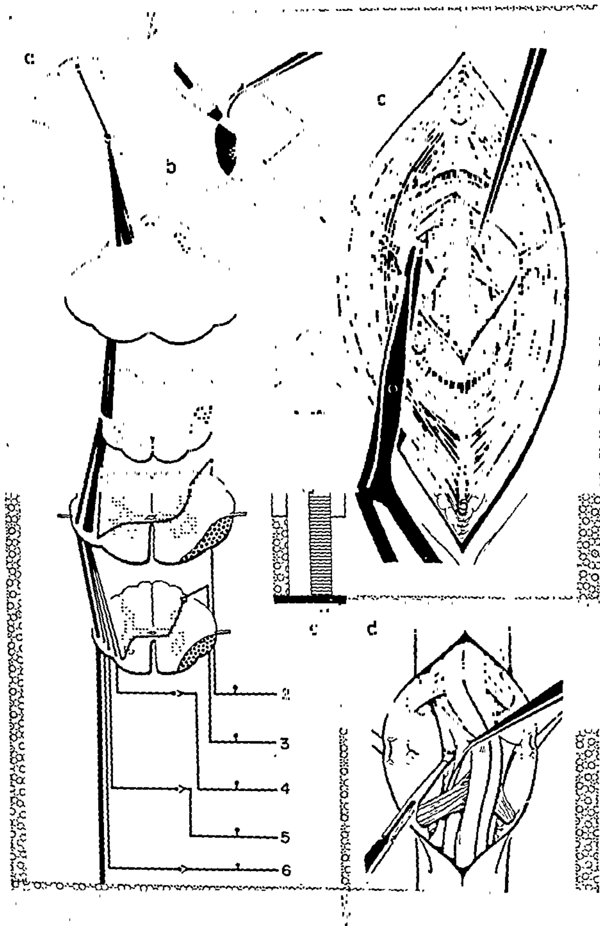
The surgical treatment for abnormal head movements classified as torticollis began first with local attacks upon the sternocleidomastoid muscle on the affected side. Attention was then given to the spinal accessory nerves supplying the anterior rotator of the head and Mayo Collier in 1890 "placed a loop of silver wire around the nerve as high as I could reach, just twisting the ends to insure slight compression." He reported a complete and permanent recovery following this procedure. Thus Keen, after cadaver dissections, sectioned the upper three cervical nerves extraspinally by a posterior neck incision. Later, in 1924, McKenzie[45a] reported a patient of Dr Cushing's, in which "an intrameningeal division of the right spinal accessory, together with the combined trunk for each of the three upper right cervical segments, was performed". He emphasized the importance of sectioning the posterior root in order to sever the afferent fibers from the muscles Although thought to be an original procedure, Dr. A S. Taylor[67a] had previously done a similar operation in 1915. Finney and Hughson in 1925 reported thirty-one cases in which a bilateral section was performed of both spinal accessory nerves and the posterior division of the upper three cervical nerves. The former were sectioned alongside the sternocleidomastoid muscles and the latter at points of emergence of the cervical nerves from the spinal vertebrae, a procedure similar to Keen's operation. There were twelve cured in this group. Dandy[19a] was impressed by these results and in 1930 suggested that the cervical root section be made through a cervical laminectomy. The spinal accessory nerves were then sectioned bilaterally in the neck Later, he spared the posterior root portion of the section in order to avoid a sensory deficit.

## Chordotomy

Chordotomy or sectioning of the lateral spinothalamic tract, which mediates the sensation of pain and temperature, may be performed in the upper dorsal area, the higher cervical region and in the medulla[60] or midbrain[70]. Operations at these various levels have been performed but the original method described by Spiller and Martin[65] is still the procedure of choice. This is an upper dorsal chordotomy which is performed at the level of the 2nd and 3rd dorsal vertebrae.

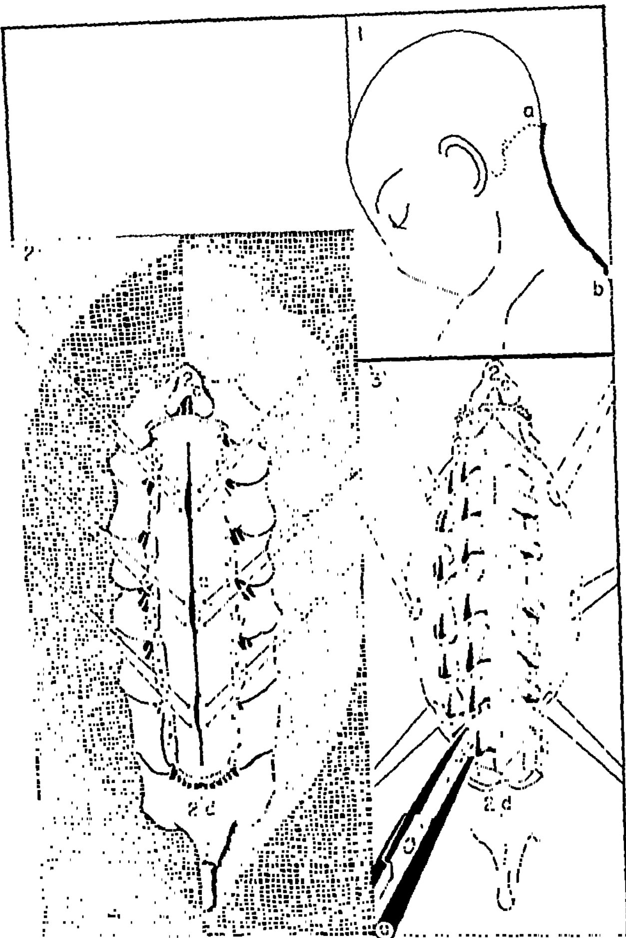
The operation dates back to William G. Spiller[64], who in 1905, presented a case report of a twenty-three-year-old man who presented tubercles in the right lateral column at the extreme lower end of the thoracic cord involving the area of Gower's tract and one about one-half to one inch higher involving the left tract of Gower. He stated that the sensation of touch was near normal in the lower limbs, but sensation for pain was abolished or almost abolished in these parts. His observations of these lesions were then related to the "location within the spinal cord of the fibers for pain and temperature sensation". In 1912, Spiller[55] reported that he referred a patient, suffering from intolerable pain with a tumor of the spinal cord, to Dr. Edward Martin for division of the anterolateral column bilaterally. By means of the Hudson trephine and the Cryer bone-cutting instrument, Dr. Martin accomplished the laminectomy and also a successful section of the anterolateral column, employing a cataract knife and making a cut 2 mm. in depth. In this period also, Cushing[17] recognized the possibility of relieving pain by interrupting the spinal cord pathways. In 1910 he suggested the possibility of "the deliberate transection of the entire cord or the posterior column alone cephalad to the lesion". In 1916 this procedure was performed with success in a patient who suffered from a breast cancer associated with spinal metastases[15]. Frazier[30] added his experiences with the anterolateral section of the cord, reporting in 1920 that he had performed the procedure in six instances, four with complete relief and two with partial relief from pain. Frazier recommended that the spinous processes and laminae of two vertebrae be removed; that the section be made four segments above the lesion and he selected the sixth thoracic segment as the most convenient site for the incision. It was recommended that the cord be rotated by grasping a dentate ligament. He estimated the distance from the surface of the cord to and including the anterolateral column as 2.5 mm. Subsequent observations have delineated the spinothalamic tract into component parts. The depth of the incision has been increased and Kahn and Peet suggest that "when an incision 4 mm. in depth is carried well anterior to the emergence of the anterior root, high levels of analgesia are obtained, and it is a rarity for such a level to fall". It was also suggested that the first and second, or the second and third dorsal laminae be removed and section made at this level. The arachnoid was opened laterally rather than in the midline. Both dentate ligaments were divided bilaterally. A blunt, thin instrument such as a knife handle, was used to rotate the cord toward the side which was being sectioned. Although disadvantages are involved in this procedure it has become accepted and standardized.

Through a median incision a laminectomy is performed involving the 2nd and 3rd, or the 3rd and 4th dorsal vertebrae. The lateral portion of the canal is removed with the help of a Kerrison rongeur to permit a *full* exposure on both sides. The dura is opened and retracted with sutures. The ligamentum denticulatum and the outgoing posterior and anterior roots are visualized. The attachment of the denticulate ligament is cut bilaterally and grasped with a hemostat on the side of the section. With care the spinal cord is rotated by means of the dentate ligament and the anterolateral portion of the cord is sectioned in an avascular area at a depth of 4–5 mm. If the procedure is to be a bilateral one, either at the same time or at a later date, anterolateral chordotomy is also done on the opposite side at a level one or two segments above or below the previously sectioned site. In *a* the position and the course of the lateral spinothalamic tract is shown. It extends to the thalamus and the position of the tract in the upper dorsal and cervical areas, the medulla and the midbrain, is shown. In *b* may be seen the extent of section to obtain complete severance of the lateral spinothalamic tract on the left side. The section is begun immediately anterior to the attachment of the dentate ligament and it is extended medial and just beyond to the emergence of anterior root fibers. Care must be taken to avoid the anterior spinal artery. In *c* is shown the extent of the laminectomy. The denticulate ligament is being cut on the left side, having already been cut on the right side. With the denticulate ligaments cut on both sides there is greater freedom for rotation of the spinal cord. At *d* is shown the rotation of the cord and section of the tract by a sharp-ended No 11 knife blade or cataract knife. The arachnoid is removed in the area for section. A No. 11 knife blade point is permitted to enter the spinal cord for 5 mm. Its further progress is impeded by a previously placed piece of bone wax at a measured distance of 5 mm. from the tip of the knife. After completing the section through the rather firm nerve tissue, it is best to re-introduce the knife through the tract to insure section of fibers that might not have been cut with the first section. The point of the knife is permitted to enter the spinal cord just ventral to the level of the insertion of the denticulate ligament and the cut is extended medially and downward as shown in *b*. The section is completed anteriorly at a point just medial to the outgoing anterior root fibers. It is *helpful to have a field free from hemorrhage and spinal fluid* at the time of section Usually, the section is made from a position on the same side of the patient. Although general anesthesia is often necessary, a more precise cut can be made under local anesthesia. Testing of the patient, if he cooperates, may then insure the adequacy of the anesthesia level. A successful section results in anesthesia for pain and temperature on the opposite side of the body at a level one to two segments below the area of section The sensation of touch, vibration and position is preserved. If general anesthesia has been used, in the absence of an adequate level of pain and temperature loss, the patient is taken to the operating room the next day and the anterolateral column cut more extensively


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Foerster has credited Victor Horsley as first to open the dura of the spinal cord and W. H. Bennett of London as the first to divide the posterior spinal nerve roots, an operation which was performed on December 20, 1888. Bennett sectioned four lumbar and one sacral nerve roots in a case of sciatica. In 1889, Abbe reported that he was asked by C. L. Dana of New York, whether "I were willing to undertake an operation conceived by him to relieve the patient of one of the most intractable neuralgias of the right brachial plexus appearing in the arm and forearm". The essential features of the operation were carried out as planned from the first by Dana. This included a section of the posterior roots of the 6th, 7th and 8th cervical nerves extradurally. The 8th root was cut intradurally at a second stage. Foerster, however, had extensive experience in rhizotomy, describing results in both gastric crises, and spastic paralysis. Twenty-eight operations were done for the former, and eighty-one for the latter, with a high percentage of successful results, which further experience however, has not duplicated. Intradural posterior root section has been accepted as a pain relieving procedure, particularly when pain involves thoracic segments and occasionally the cervical and lumbar roots. In intractable lumbar root pain, limited to one or two roots, the result of neoplastic or recurrent intervertebral disc disease, such an operation may be valuable.

A cervical rhizotomy may be necessary for intractable pain of an upper extremity from cancer of the breast involving the brachial plexus. A laminectomy is performed through a midline incision of the neck and the occipital scalp. This may be performed with the patient in the sitting position under intratracheal anesthesia. The incision extends from just below the occipital protuberance to the 2nd dorsal spinous process, *1a* to *b*. The 2nd, 3rd, 4th, 5th and 6th cervical spinous processes are bifid. The ligamentum nuchae is incised preparatory to separation of the muscles from the spinous processes and laminae. Any bleeding points in this region are stopped by electrocoagulation. The laminectomy may be done unilaterally or bilaterally. A unilateral laminectomy is adequate and can be carried out with dispatch. A bilateral laminectomy is shown in the accompanying figure. In order to denervate completely the upper extremity on the affected side, as well as the neck, the posterior roots of the 3rd through and including the 2nd dorsal nerve should be cut. This will necessitate a hemilaminectomy or laminectomy from the 2nd cervical to the 2nd dorsal lamina. After removal of the spinous processes with a straight double-acting rongeur, the laminae in this region are removed In a cervical laminectomy the laminae are thin and can be engaged with ease with a goose-neck rongeur The laminectomy is extended laterally, particularly on the side of the rhizotomy. In *2* the laminectomy has already been performed, the dura has been exposed and incised between silk sutures In *3* the dura is retracted. The dorsal roots are separated from the ventral roots and after the application of silver clips they are sectioned All of the fibers in the dorsal root are completely sectioned. The sectioned dorsal roots


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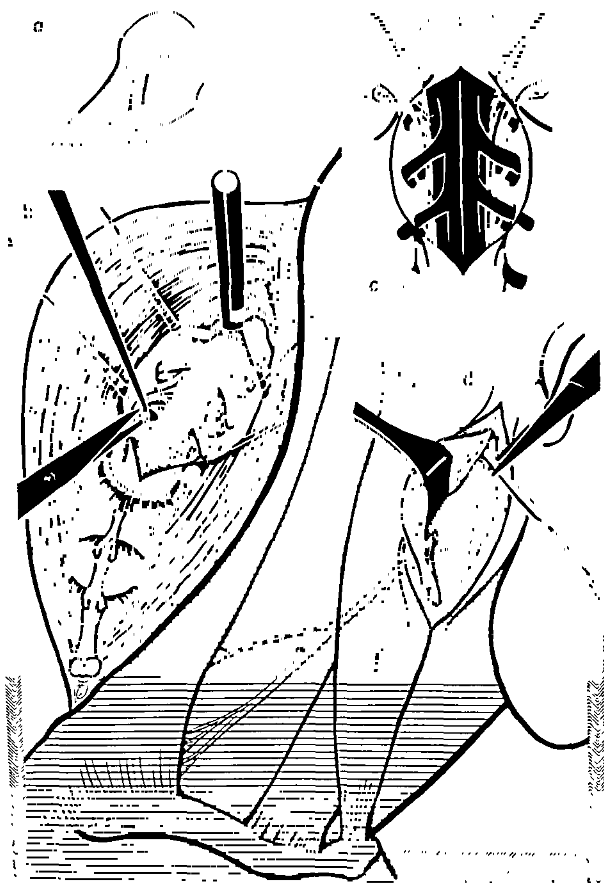
and the intact ventral roots are shown and the denticulate ligaments which separate them. After such an operation the entire extremity is made anesthetic. Although there is no motor paralysis, the extremity is quite useless as far as voluntary activity is concerned, and this result is an important disadvantage of the operation.

## Cervical anterior rhizotomy and section of the 11th cranial nerve

▶

Section of the upper three cervical anterior roots as well as section of the 11th cranial nerve extracranially is a procedure performed in some patients with spasmodic torticollis and allied torsion states. This operation may be accomplished with the patient in the sitting position, much better than in the prone position. Intratracheal anesthesia is usually preferable. In *a* the position of the incisions on the back and on the side of the neck are shown. The laminectomy incision extends from the external occipital protuberance through the midline down to the 5th and 6th cervical spinous processes. After retraction of the semispinalis capitis and splenius capitis muscles, the spinous processes of the 2nd, 3rd, and 4th cervical vertebrae and the posterior arch of the atlas are exposed. As the bifid spinous processes are separated from their tendinous and muscular attachments, the longissimus cervicis and multifidus muscles are carefully separated from the laminae and spinous processes of the 2nd, 3rd and 4th cervical vertebrae. The posterior arch of the atlas is also cleared bilaterally by reflecting the rectus capitis minor and the rectus capitis major muscles. A portion of the occipital squama about the foramen magnum is also exposed. After retraction by self-retaining retractors the spinous processes of the 2nd and 3rd are removed. This is followed by excision of the laminae. The posterior arch of the atlas is also removed. The spinal canal is exposed as far laterally as possible, to facilitate the visualization of the posterior and anterior roots when the dura is opened. As shown in *b* the dura has been opened and retracted. The posterior roots are separated from the anterior roots, the line of division being the denticulate ligaments Usually there is no posterior root in the 1st cervical nerve The anterior root of this nerve is quite high and may be easily missed, if a portion of the foramen magnum has not been removed and the dural incision extended up into the region of the cisterna. If there are bleeding points the use of clips is recommended. Some surgeons prefer sectioning both the posterior as well as the anterior roots. It is important to avoid cutting the anterior root of the 4th cervical since this may embarrass respiration due to the phrenic supply being interrupted.

In *d* the exposed 11th cranial nerve supplying the sternocleidomastoid and trapezius muscles is shown on the lateral aspect of the neck. This nerve is best exposed by a dissection of the proximal third of the sternocleidomastoid muscle on its internal surface As this is done the 11th cranial nerve is found to enter the medial surface of the muscle at the junction of the upper and the middle third of the structure. The use of a stimulator expedites its location. The discussion of the exposure of this nerve is given on page 384.



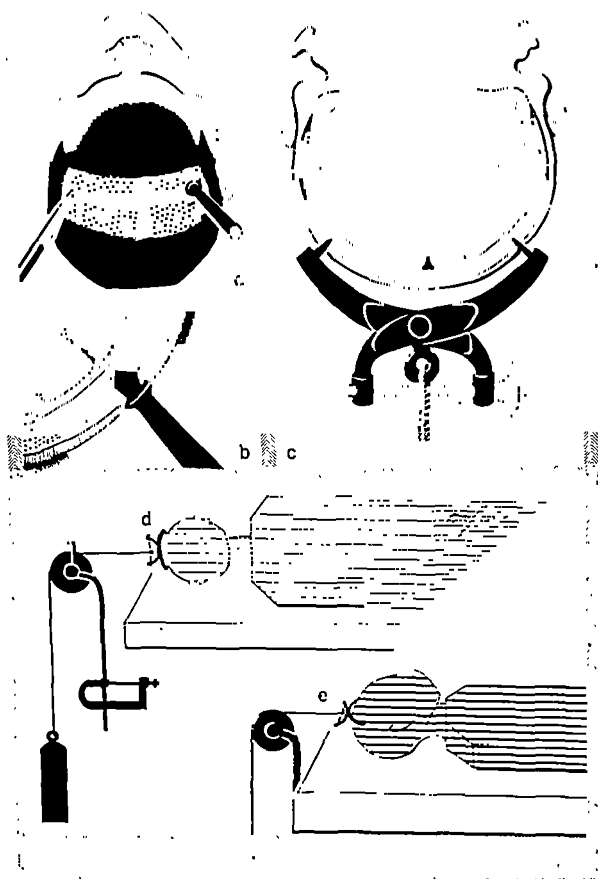
A new method for skeletal traction in the treatment of dislocation of the cervical spine was reported by Crutchfield[33] in 1933. Older methods had included manipulation of the cervical spine with halter traction as employed by Taylor[64]. Plaster jackets, collars, braces were used with and without manipulative reduction. Since Crutchfield's patient had sustained a compound fracture of the mandible, it was stated that traction against the chin and occiput could not be used and at the suggestion of Dr. Coleman, extension tongs, termed "Edmonton extension tongs", with the sharp points removed, were used on this patient who presented a total dislocation with overriding of the bones, in the cervical spine.

Two years later, K. G. McKenzie also arrived at the same conclusion that skeletal traction had an important advantage when applied by means of tongs instead of a halter. He reported several cases treated by what were described as "ice tongs" applied by "tapping with points through the outer cortex of the skull just above the lobes of the ears".

Although other methods have been tried, such as the insertion of hooks under the zygomatic arches with traction, suggested by Neubeiser, or the insertion of a wire extradurally through burr holes in the skull with traction, suggested by Hoen and Cone and Turner, the most satisfactory form of treatment as well as the most suitable instrument was described by Crutchfield[15] again in 1938. The directions given for the correct placement of the tongs included "the use of lines painted on the scalp to indicate the midline of the skull and the approximate plane of the cervical articulations (above the mastoid tips). With the traction bar resting on the midline the points of the tongs are brought down upon the transverse line. These points of contact are marked for the placement of stab wounds. After injection of novocaine, one per cent, stab wounds just large enough to admit the drill guard are made down to the skull. The drill point is forced to a depth of 3 mm. in children and 4 mm. in adults. The fixed guard prevents excessive penetration. The points of the tongs are fitted into the bone perforation and held in position until the tongs have been locked".

The application of Crutchfield tongs is a frequent necessity in neurosurgical practice for patients with fracture-dislocation of the cervical spine associated with spinal cord or root injury. This is preferable to halter traction Cervical traction may also be required in injuries to the cervical spine without neural involvement.

In *a* the position of the puncture wounds in the scalp is outlined after holding the Crutchfield tongs in proximity to the head and in line with the upper and anterior border of the ear. With a No 11 blade knife puncture wounds are made after shaving the hair immediately around this region, and injecting 1 per cent novocaine The puncture wound should be large enough to permit the introduction of the special Crutchfield drill used for this purpose In *b* the position of the protecting rim of the drill is shown. Only the outer table of the skull and a portion of the diploe is thus traversed The holes in the skull are made in a plane parallel to the points of the tongs.


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In *c* the position of the tongs in relation to the thickness of the skull is shown with the tongs in place. In *d* and *e* traction in the anteroposterior and lateral positions is shown. After application of the tongs the clamp is secured and tightened in position. The wounds about the points of the tongs are covered by gauze with collodion. If necessary, this application of tong traction may be carried out without moving the patient to the operating room. A Stryker or some such suitable frame for frequently changing the position of the patient is also essential in the management of patients with fracture-dislocations of the cervical area with involvement of the spinal cord.

## Bullet and other penetrating wounds of the spine

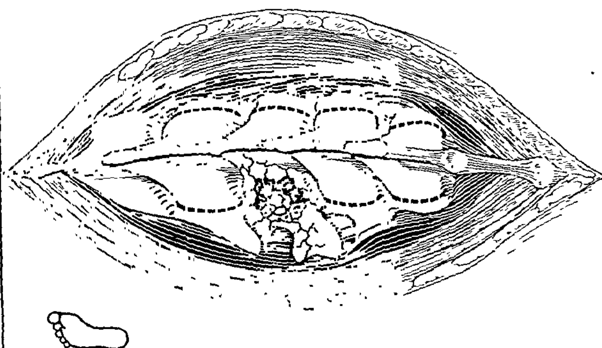
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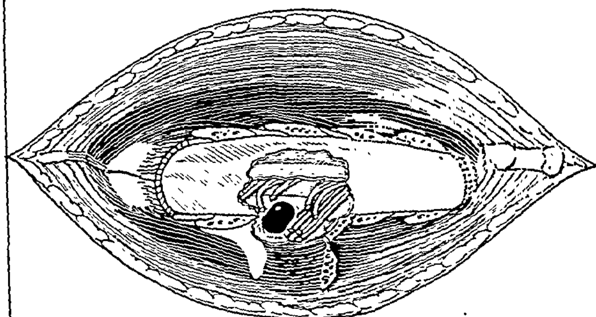
An example of a penetrating wound of the spine by bullet injury with involvement of the spinal cord is illustrated in the next two plates. At *a* the spine has been exposed for laminectomy. The wound of entrance is carefully debrided. A wide laminectomy is indicated and an exposure of two vertebrae above and below the site of injury is desirable. The use of a gooseneck rongeur, Taylor rongeur and the Kerrison is recommended.

In *b* the laminectomy has been performed. Five laminae have been removed. The dura is found to be torn by the passage of the bullet. The nerve roots, as well as a portion of the spinal cord are found involved. Careful dĕbridement of the tissues damaged by the foreign body and fragmented bone is done without adding additional injury. The dura is debrided with a scissors or knife. The destroyed and lacerated nerve tissue is excised. Foreign debris and bone fragments are removed. The bullet, if accessible, is removed. In many instances the bullet has lodged beyond the operative site. Its removal may be unnecessary since tissue tolerates inorganic material but not organic substance Large, irregular, shrapnel fragments, which carry contaminated material into the body, always should be removed.

Fractures, and fracture-dislocations, as well as penetrating wounds of the spine may be associated with involvement of the spinal cord, cauda equina and nerve roots. Two main classes of injuries occur: First, "closed" injuries of the spinal cord or cauda equina produced by fracture, fracture dislocations or concussions; and second, open or penetrating wounds of the spinal cord or cauda equina produced by high or low velocity missiles, including bullets, shell fragments, knife stabs, etc Most patients in group two require surgical treatment, whereas in group one there may be occasional need for laminectomy. Surgical treatment in group one is indicated if there is a spinal fluid block upon manometric study, with cord compression. A progressive or dynamic syndrome of increasing disability following the injury also indicates the need for exploration. Some authors prefer rapid hyperextension instead of laminectomy Cervical fracture dislocations are treated by means of traction with Crutchfield tongs

The patient in group two should have debridement and laminectomy only when his general condition permits. Debridement and laminectomy in open wounds are indicated in the presence of bone and/or metallic fragments within the spinal canal, a spinal fluid block, or spinal fluid leakage. In the presence of increasing symptoms following a penetrating wound, surgical exploration at the level of the injury as soon as practical, is indicated


a


b

In *c* the position of the tongs in relation to the thickness of the skull is shown with the tongs in place. In *d* and *e* traction in the anteroposterior and lateral positions is shown. After application of the tongs the clamp is secured and tightened in position. The wounds about the points of the tongs are covered by gauze with collodion. If necessary, this application of tong traction may be carried out without moving the patient to the operating room. A Stryker or some such suitable frame for frequently changing the position of the patient is also essential in the management of patients with fracture-dislocations of the cervical area with involvement of the spinal cord.

## Bullet and other penetrating wounds of the spine

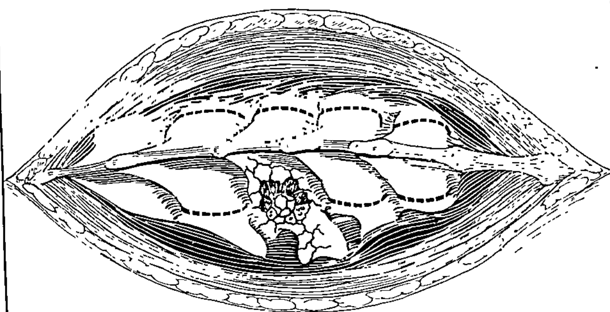
▶

An example of a penetrating wound of the spine by bullet injury with involvement of the spinal cord is illustrated in the next two plates. At *a* the spine has been exposed for laminectomy. The wound of entrance is carefully debrided. A wide laminectomy is indicated and an exposure of two vertebrae above and below the site of injury is desirable. The use of a gooseneck rongeur, Taylor rongeur and the Kerrison is recommended.

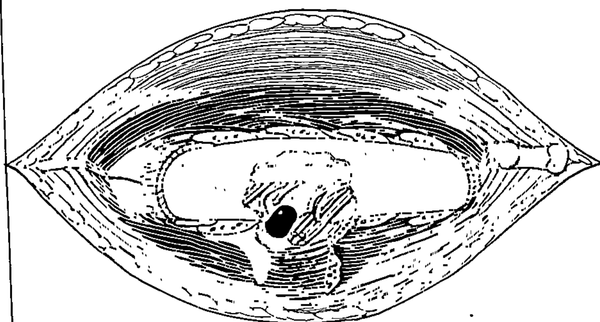
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a




b

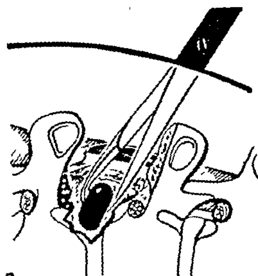
The management of spinal cord injuries includes the care of the skin which is aided by placing the patient on a Stryker frame and turning him at two-hour intervals. If such a frame is not available frequent changing of the position in bed is essential. An air mattress may minimize decubiti. The skin is kept dry and clean. If a hyperextension cast has been used it should be bivalved as soon as possible and the upper and lower portions removed at turning. A cast should not be applied until abdominal distention has subsided. All pressure points must be properly padded. Decubiti should be treated by exposure to light and air with excision later if necessary.

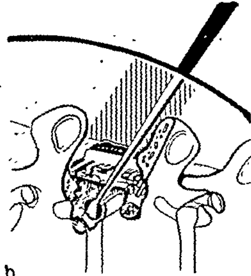
A second important matter is the care of the bladder which is managed by an indwelling urethral catheter. A tidal drainage apparatus is employed in conjunction with the catheter. The patient may be trained to irrigate the bladder manually twice or three times a day with boric solution. Antibiotics may be used to prevent or treat bladder infection. The catheter is removed, cleaned and sterilized and reinserted every ten to fourteen days. As soon as possible the catheter is removed. Cystometric studies are important and should be performed under the direction of a urologist.

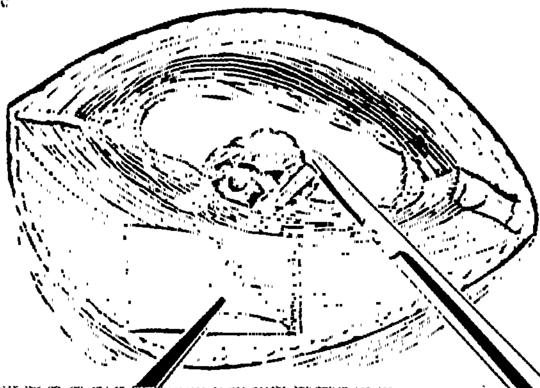
The third important point is attention to the patient's morale. He is encouraged from the outset to help himself in personal care, moving and turning, and instructed early in the fundamentals of rehabilitation. The physical and vocational therapists must begin their program as early as possible. Finally, rehabilitation is instituted as a collective effort by the neurosurgical, orthopedic, urologic and physical medicine consultants, administering an integrated program for producing ambulation as soon as possible. The patient must be supplied with an incentive to accomplish this step For the heavy expenditure of effort necessary to make this possible on his part he must be taught a productive occupation.

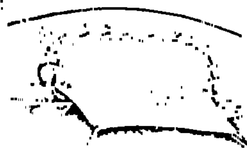
The neurologic evaluation of the patient with a spinal cord injury should be frequent, particularly in cases where there may be increasing symptoms and signs of spinal cord or cauda equina dysfunction. If the patient has complete sensory loss from the level of the injury downward, with an areflexic paraplegia and sphincter paralysis, profound injury has been sustained. If such a neurologic picture remains constant for over twenty-four hours, the possibility of irreparable damage cannot be denied. However, in many instances there may be partial motor and sensory paralysis with or without sphincter disability. The patient may have evidences of nerve root involvement, particularly in cervical fracture dislocations with pain and disability involving the upper extremities on one or both sides. These states require individual evaluation as to the value or advisability of surgical treatment. The use of spinal puncture, manometric studies and pantopaque* for myelography are important aids in such an evaluation In closed injuries, cervical cord damage may be produced by a rupture of a disc which may be revealed by myelography

In *a* a lateral view of the area of the bullet wound and the extraction of the


a


b


c





bullet with long grasping forceps is shown. In *b* the area of the bony tract in which the bullet was lodged is curetted. In *c* a piece of the lumbodorsal fascia is used to close the defect in the dura. The dural edge is shown being debrided with scissors. The free graft of lumbodorsal fascia is sutured into place with interrupted silk sutures. The destroyed bits of tissue from the spinal cord are removed mainly by irrigation. Care must be taken not to injure the spinal cord by manipulations in sponging, extracting bone fragments, etc. After suturing the dura, on the dorsal and lateral aspects of the spinal cord, the graft may be tucked under the spinal cord with a stitch or two taken through the anterior dura and through the free graft, making possible a tight closure of the area.

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## *Spina Bifida—Historical*

The literature of the 19th century emphasized the futility of surgical treatment of congenital defects involving the spine, associated with herniation of the meninges, with or without neural tissue. It was held "that active surgical treatment usually hastens death". Because of the free communication between the sac of the congenital defect and the subarachnoid space of the spinal canal, "every active surgical measure would almost certainly be followed by diffuse inflammation of the spinal membranes or gangrenous softening of the cord". A conservative method of treatment inherited from the past employed the use of simple compression, later combined, as suggested by Abernethy, with repeated punctures of the tumor. Sir Astley Cooper reported two successes by this method of treatment. Tapping was done with a fine trocar and the mass was only partially emptied It was customary to paint the skin overlying the mass with collodion.

More active measures in dealing with this congenital abnormality included injection, ligature and excision Brainard of Chicago, in 1848, suggested the injection of iodine into the sac without emptying the sac completely. Velpeau used this method, modifying it. He withdrew all of the fluid from the sac and injected the iodine. Ligation of a bifida pedicle with occasional success was reported. The sac was permitted to slough distal to the area of ligation. Dubois suggested the use of a clamp for this purpose. Two narrow steel plates, regulated by screws placed about the pedicle of the mass, resulted in gradual and complete strangulation. Excision of the sac was only used as a last resort. Childs opened the spina bifida, pushed the collapsed parieties back into the canal and united the soft parts over, tightly enough to prevent reprotrusion of the sac. Holmes thought that this was more dangerous than excision.

In the beginning of the twentieth century, a surgical evaluation of treatment developed Other indications for surgical treatment were tabulated Frazier[29] in 1918 described a simple closure of the spinal canal by apposition of adjacent soft tissues, after excision of the sac.

## Spina Bifida

### Meningocele and Myelomeningocele

Spina bifida may be defined as a defect in the spinal column, either posteriorly or anteriorly, with or without protrusion of the linings of the spinal canal, the spinal nerves, and the spinal cord itself. Various types of spina bifida are shown in *1*. At *a* is a meningocele, with only a protrusion of the membranes of the spinal canal. This protrusion may be covered with fine, thin skin, or with a thick, well developed skin. In some instances there may be an associated lipomatous accumulation about the sac, making the mass, resulting from the meningeal herniation, much larger in appearance than it actually is. The management of such a meningocele is simple and may result in recovery without any neurológical deficit. In *b* is shown an example of a myelomeningocele, where the spinal cord and nerves arising from the spinal cord are in the hernial sac. Such a case almost always is associated with severe neurological deficit. Usually, where the spinal cord is attached to the underside of the sac lining, there may be an ulcer on the external surface of the mass. Such an ulcerating area is almost always an indication of the presence of a myelomeningocele. In many instances the myelomeningocele sac is very thin and, as stated, may be associated with an ulcerating surface. In *c* is shown another example of a meningocele, which is usually seen in the lower cervical or upper dorsal region, where the hernial sac is almost completely closed and only a very small communication exists between the sac and the spinal canal. In *d* is shown an example of spina bifida occulta, where only a small portion of the spinal column may be defective. This may be anteriorly or posteriorly. Such a lesion is almost never suspected and may be an "x-ray find". In other cases the presence may be suspected by the appearance of a lipomatous swelling in the vicinity and also hypertrichosis. In *e* is shown another example of spina bifida occulta which to all intents and purposes is never suspected except possibly by x-ray examination of the spine, where small defects of the arches of the vertebrae may be noted on x-ray examination.

The presence of paralysis in the lower extremities, sphincter paralysis or the presence of a hydrocephalus, all are contraindications to intervention in cases of spina bifida. Occasionally, the spina bifida may be huge and it may be desirable to excise the mass in order to make it possible for the parents to manage the patient with greater facility. Under such a circumstance it should be definitely understood by the parents that the operative intervention should not be considered a treatment for the paralytic condition.

The presence of a spina bifida may be considered an evidence of defective spinal fluid absorption. Under these circumstances the repair of the spina bifida with complete excision of the soft spongy tissue bed about the neck of the sac near the spine, may be undesirable. With complete excision there may be a greater likelihood of hydrocephalus. In the repair of spina bifida almost always there is sufficient amount of tissue to obtain a good closure.

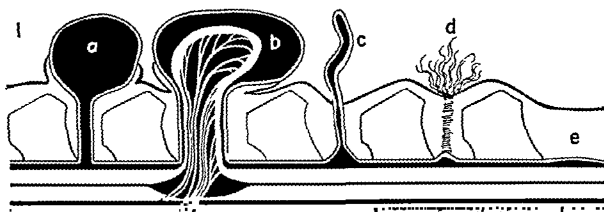
*In some instances it may be necessary to undermine the skin for long distances to obtain a good approximation.* In other cases there may such an extensive defect about the open spinal canal that it would be impossible to close over this area of defect without using a reflected portion of the latissimus dorsi muscle as we have shown in the accompanying figures. The ideal for operative intervention is a complete and tight closure which will heal without the formation of a fistulous tract. The surgical management of a spina bifida with meningocele is seen in the accompanying illustrations. The incision is made from side to side, and encircling the base of the meningocele, *2*. After exposing its neck the sac now is opened and the contents inspected. If the contents are devoid of any nerve tissue, then the sac is amputated, and as shown in *3* the neck of the sac is closed, beginning at *c*. The membrane of the sac is shown at *a*. The excess membrane is excised. A lumbodorsal fascial flap may be used to close the defect and the dotted line at *d* shows the extent of the incision in the lumbodorsal fascia on either side As shown in *4*, after having closed the neck of the sac at *a* the lumbodorsal fascia at *b* is dissected and pulled over the defect and sutured as shown in *5* at *a*. The iliocostalis muscle is seen at *b*, and *c* is the closure of the skin in two or three layers. It is important to undermine the skin sufficiently to get an approximation without tension.

In the evaluation of patients with spina bifida for operative intervention, the condition of the lower extremities, the condition of the sphincters, the presence of abnormalities of the head and lower limbs are important criteria. In the presence of paralyzed lower limbs, paralyzed sphincters and beginning or already present hydrocephalus, intervention should not be carried out. The condition of the skin overlying the spinal defect is also important at the time of operative intervention. *If the skin is quite thin the earlier the intervention the better.* Many of our patients have been operated upon within the first twenty-four hours after birth. Among those who have no paralysis of the lower extremities there may be a discharging wound through rupture of a thin membrane. In this group, penicillin and chemotherapy for three days prior to operative intervention is now used. At operation such wounds are closed without drainage and heal by primary intention.

*The Dura Mater of the Spinal Canal*

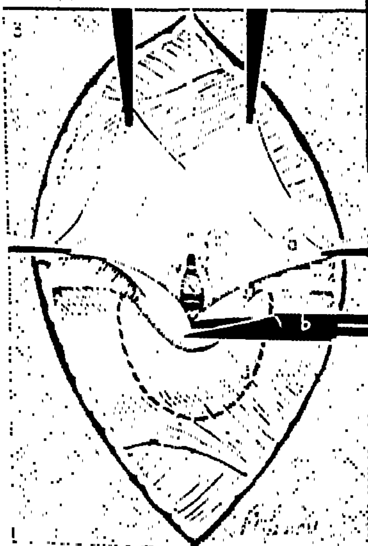
The dura mater of the spinal canal is a continuation of the inner or the meningeal layer of the cranial dura. It extends from the foramen magnum to the coccyx The portion containing the dural and subarachnoid spaces ends at the second sacral vertebra where the dural lining becomes fused with the filum terminale externum. The subdural space *is a potential cavity containing a very minute quantity of fluid serving to moisten the surfaces in apposition.* The epidural space contains varying quantities of loose connective tissue filled with a plexus of venous

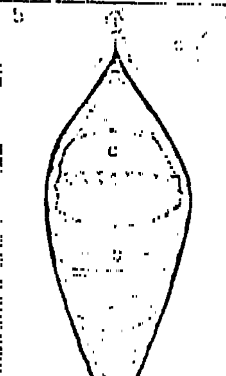
*(Concluded on page 302.)*


1
a
b
c
d
e


2




b

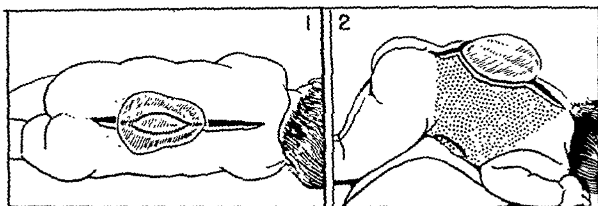


In some cases a myelomeningocele may have to be operated upon. The myelomeningocele as shown in *1* is much more extensive supero-inferiorly than from side to side, consequently a supero-inferior incision should be utilized. Such an incision should extend from about the base of the neck to about the coccygeal area, encircling the base of the spina bifida. The extent of this incision and its direction is shown in *1* and *2*. The dotted area in *2* is to portray the extent of undermining that may be necessary in order to approximate the skin edges at the conclusion of the operation. In some of these patients we have undermined the skin almost all the way to the linea alba on either side. It is important to undermine the skin between the subcutaneous fascia and the lumbodorsal fascia so as not to disturb the blood supply unduly, as this may result in gangrenous defects of the skin. In *3* the neck of the sac has been dissected free at the base of the spina bifida. As is usually the case, the lining of the sac posteriorly is very thin and there may be an ulcerating area on its external surface. The ulcerating area has to be excised and almost always one finds on the internal surface of the ulcerating area attached neural tissue, usually spinal cord and nerves. It is important to separate carefully the spinal cord and nerves from the area of ulceration. In some instances it may be necessary to excise a portion of neural tissue to obtain this separation. Such a separation is obtained after first exposing the contents of the sac at the neck or more peripherally towards the dome of the sac. By widely opening the sac one now has good exposure of the pathological anomaly and a good estimate of what is needed. In *a* the sac has been widely opened and in *b* the spinal cord, which is attached to the wall of the sac, is carefully separated from the sac wall. In *c* the connection of the neural tissue to the ulcerating area is being severed. There may be some bleeding points and these may be stopped either with silk sutures or a piece of gelfoam. After the contents of the sac have been separated from the wall the sac is excised and the contents are now permitted to fall into the spinal defect as in the illustrated instance between the 11th dorsal and the 3rd lumbar vertebrae.

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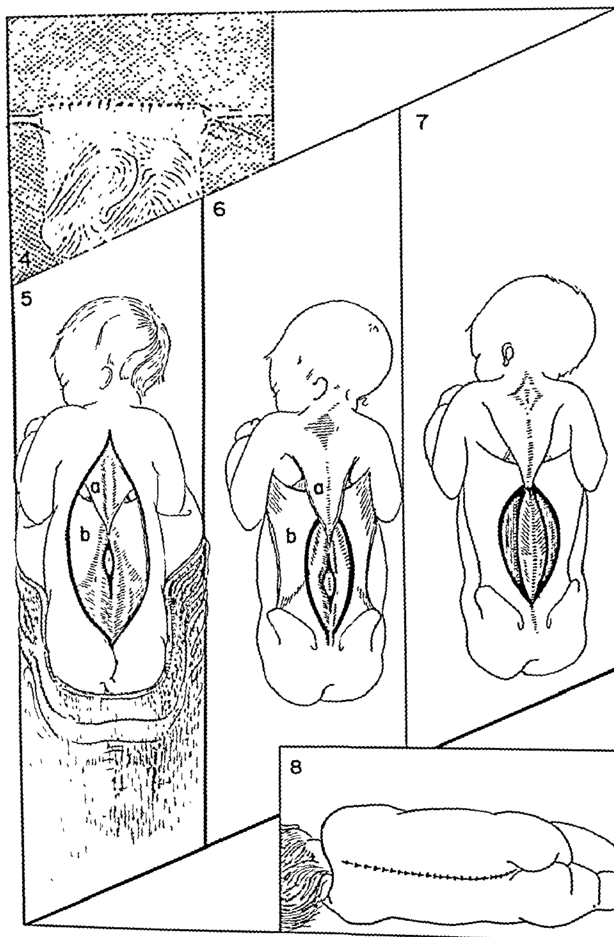
*The Multifidus, the Interspinal, and Intertransverse Muscles*

The multifidus consists of muscular and tendinous tissue arising from the transverse processes of the lumbar, dorsal and cervical vertebrae, and inserting into the entire surface of the spinous processes above. They may connect either consecutive vertebrae or a given transverse process with the spinous process of two or three vertebrae above. The interspinous muscles are best developed in the cervical area where they form two distinct muscles attached to the bifid spinous processes. The intertransverse muscles are found between the transverse processes of the various vertebrae.


1
2
3
b
a
c

Following the separation of the neural tissue and permitting this tissue to fall into the canal, the dural lining is now sutured over this mass of tissue. The dural lining is usually very thin and spongy, and although a good closure is possible, a water-tight closure is probably never obtained, because of the spongy and porous character of this lining. To cover over this area of defect, a reflected portion of the latissimus dorsi and what is left of the lumbodorsal fascia may be used. In *5* at *a* one sees the lowermost end of the trapezius muscle on both sides. At *b* is the latissimus dorsi muscle. After incising the latissimus dorsi under the undermined skin, as shown in *6* at *b*, one can pull the muscular fascial layer to the midline and suture it to its fellow similarly obtained on the opposite side. This is a water-tight closure. It is impossible to obtain the same type of closure by using the lumbodorsal fascia, both because it is very thin and also because a great deal of it is already lost in the defect of the spinal canal and its attachment to the latissimus dorsi is now already more or less muscular. Consequently, this layer of muscle tissue appears to us to be the best type for closure over the defect. When the skin has been undermined almost completely around the periphery it is a simple matter to approximate it in layers. Such an approximation should be without tension so as not to produce necrosis of the sutured edge. *In 8 the closure and the extent of the incision are shown. In some* cases, loosening incisions into the skin in the form of a stab wound may be made in the anterolateral portion of the abdomen. This was rarely necessary in the majority of our patients. It was possible to approximate the skin edges without much difficulty.

In the postoperative management of spina bifida, the wound may be exposed to the air without any dressings and the entire body may be placed under a light cradle. Healing seems to take place much more efficaciously under these dry circumstances. It is important to make sure that the temperature of the cradle is not up too high High fevers may be imparted to an infant if this is not watched carefully. The patient should be kept on his face in a prone position and in this way, excreta will not contaminate the wound At times it may be necessary to tie the hands and feet to the bedding in such a manner that the patient is held in the face-down, flat position If there is some necrosis of the skin edge of the repaired spina bifida it is usually not too extensive and it heals by secondary intention It has not been found necessary to skin graft such an area. However, this may be done if desired.


4
5
6
7
8
a
b
a
b

## Cranium bifidum. Craniomeningocele or encephalomeningocele ▶

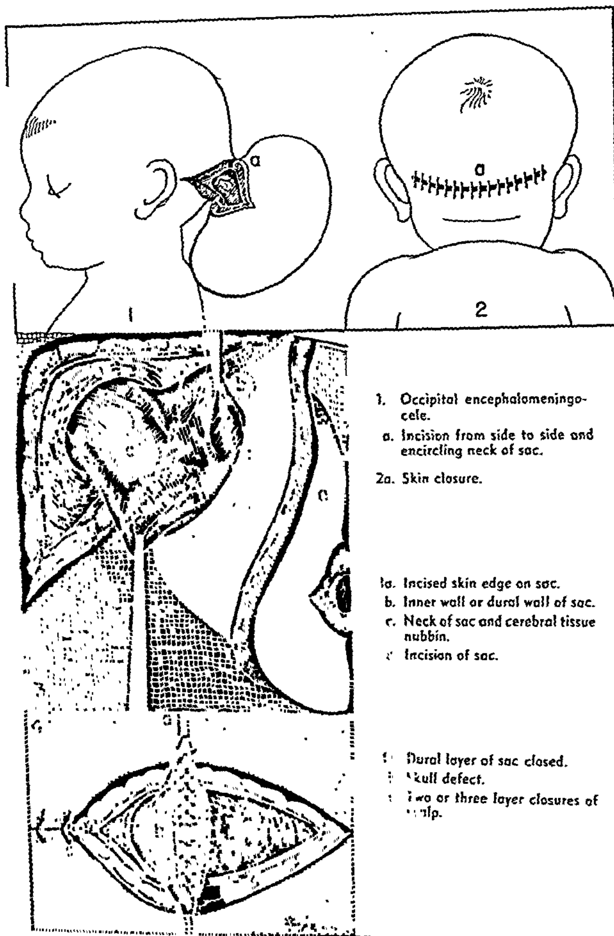
Cranium bifidum is a defect of the skull usually at the midline with herniation of the meningeal linings of the brain with or without herniation of cerebral tissue. Almost always this is in the occipital area in a posterior position but it can also occur in the anterior aspect of the head, through the mouth and the roof of the nose. In cranium bifidum, the patients almost always have associated defects in the central nervous system and the results following repair of such a lesion are not as satisfactory as in many instances of spina bifida. The lining of a meningocele sac may be thin, particularly with the large meningoceles of the midline occipitospinal area. The meningocele can be easily transilluminated. The contents may be evaluated on this basis. In other instances, particularly with a smaller encephalomeningocele, the skin lining is much more sturdy and normal in appearance. The surgical management of such a case is best deferred for four to six months. On the other hand, if the lining of the sac is of a cigarette paper thickness and the likelihood of a rupture is imminent, then the operation may be performed promptly. Many such cases are operated on the second or third day following birth. If a cranium bifidum or a spina bifida has already ruptured, the patient is placed on antibiotics and sulfanomides, for two or three days prior to operative intervention. Usually, primary healing takes place following excision of the mass.

In the accompanying figure, an encephalocele in the occipital area has been pictured. In *1* the position of the mass and the incision at its base from side to side and encircling the base are shown. Following closure of such an incision there is a line of repair as shown at *a* in *2*. The neck of the sac is carefully exposed as shown in *3*. At *a* is seen the skin edge which has been reflected, exposing the outer surface of the inner lining of the sac which is at *b*. The neck of the sac in now incised and the cavity of the sac is inspected. At *c* a small nubbin of nervous tissue is seen. After noting that the sac does not contain any other neural tissue, it is cut at *d*. The neck of the sac and the dural lining are now closed with interrupted silk suture as shown in *4a*. This may be followed by a fascial closure immediately over the area of the defect in the bone at *b*. Depending upon the position of the defect, this may be covered with musculofascial tissue of the skull. In rare instances it may be necessary to obtain a free graft of temporal fascia to close the opening. The skin is then closed in two or three layers over the area as shown in *4c*.

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*Dura mater of the Spinal Canal (concluded)*

channels. When an intradural tumor is encountered, the epidural fat is usually completely lost by compression. The epidural fat and its venous channels may cause bleeding difficult to control in laminectomies. Careful hemostasis is essential to prevent epidural hemorrhage which can compress the spinal cord and destroy its function.




1. Occipital encephalomeningocele.
 a. Incision from side to side and encircling neck of sac.

2a. Skin closure.

1a. Incised skin edge on sac.
 b. Inner wall or dural wall of sac.
 c. Neck of sac and cerebral tissue nubbin.
 [illegible] Incision of sac.

[illegible] Dural layer of sac closed.
[illegible] Skull defect.
[illegible] Two or three layer closures of scalp.

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# AUTONOMIC NERVOUS SYSTEM

# Historical Considerations

THE NAMES of Galen, Vesalius, Eustachius and Willis are linked to the anatomical identification of this system. The term "sympathetic" was used by a Danish anatomist, Winslow, in 1732.

Basic physiologic knowledge was reported by Bichat in 1802, Bernard and Brown-Séquard in 1852. The work of Gaskell, beginning in 1886, and Langley, 1889, completed concepts which are still tenable. The former introduced the term "involuntary nervous system". He recognized a dual but antagonistic control provided by this system, "one katabolic, the other anabolic". Langley suggested the term "autonomic nervous system", designating "sympathetic and parasympathetic" divisions. The role of mediators, chemicals secreted at the nerve ends, for each system, has been a more recent discovery by Loewi and Cannon.

The application of surgery to the sympathetic system was first made in the treatment of epilepsy by Alexander, reported in 1889, who removed the superior cervical ganglion. Others, as Jonnesco, 1896, Jaboulay, 1899, removed portions of the cervical sympathetic chain in treating epilepsy, a procedure which was still performed in 1931 by McClintic. Other diseases treated similarly were Parkinsonism, exophthalmic goiter, glaucoma, retinitis pigmentosa, facial neuralgia, migraine, and facial paralysis. More recently, the treatment of cerebral thrombosis and "spasm" of cerebral vessels has involved interruption of function of the cervical chain by anesthetic block. Causalgia has been relieved by attack upon this system.

Francois-Franck in 1899 reported upon the value of resection of the thoracic portion of the sympathetic chain for angina pectoris. Leriche used cervical and stellate ganglionectomy with some favorable results. A more satisfactory procedure has been the resection of the stellate and the thoracic ganglia to the fifth (White, Garrey and Atkins).

Attempts to improve the circulation of the upper extremities by an upper thoracic sympathectomy resulted earlier in temporary benefit (Adson and Brown, 1929). A posterior approach was used for this resection. The poor results were attributed to adrenalin sensitive arteries, related to the postganglionic type of chain removal. A preganglionic type of procedure was found to be more satisfactory (Smithwick). Telford has recommended an anterior approach for a preganglionic type of operation.

Hunter and Royle, 1924, employed resection of the lumbar sympathetics

in the treatment of spastic paralysis. The resulting increase in blood flow in the extremities suggested the value of the procedure in the treatment of other peripheral vascular diseases. Adson and Brown in 1925 performed a bilateral lumbar sympathectomy for Raynaud's disease by an intra-abdominal approach.

An extraperitoneal operation, as illustrated on p. 348, was suggested by Flothow in 1935.

Vascular lesions involving the lower extremities were treated by lumbar sympathectomy with varying success. These included thromboangiitis obliterans, arteriosclerosis, reflex dystrophies, hyperhidrosis, causalgia, embolism and thrombophlebitis.

The possibility of employing resection of the sympathetic nervous system for hypertension was a theoretical consideration until recent years. In 1925 Rowntree and Adson used a bilateral lumbar resection. Craig and Peet both used a splanchnic nerve resection, the former by an infra- and the latter by a supradiaphragmatic approach. Gradually more extensive procedures, which removed the splanchnic nerves and portions of the sympathetic chain, were used. Smithwick removed the sympathetic chain from the 8th thoracic through the 2nd lumbar ganglia. Others have done total sympathectomies in stage procedures.

Resection of the presacral nerve by an intraperitoneal approach was held to be of value in the treatment of dysmenorrhea and painful affections of the urinary bladder (Learmonth, 1931 and Cotte, 1925).

The limitation of this procedure as an effective pain relieving operation has gradually been recognized.

# Anatomy and Physiology

THE AUTONOMIC nervous system is often referred to as the vegetative nervous system and has been considered as a separate mechanism apart from the central nervous system, being composed of sympathetic nerve trunks with communicating plexuses. More recent physiological information has revealed important connections between the central nervous system and the autonomic system related to centers present in the diencephalon and the cerebral cortex.

The autonomic nervous system is composed of two divisions as described by Langley, namely the sympathetic and the parasympathetic. The sympathetic portion is distinguished from the parasympathetic by the former having cells of origin in the thoracic and upper three lumbar segments of the spinal cord. The parasympathetic portion originates from the brain stem and the second, third and fourth sacral cord segments. Thus, the sympathetic system is described as the thoracolumbar, while the parasympathetic is identified by the term, craniosacral. The cells of origin of the sympathetic fibers are in the intermediolateral column of the spinal cord. These preganglionic fibers, which are myelinated, traverse the ventral roots as white rami communicantes and reach the ganglia of the sympathetic chain, located on the lateral aspect of the vertebral bodies. From the ganglia, there arise the postganglionic fibers which are unmyelinated and these gray rami communicantes join the peripheral nerves providing innervation to blood vessels and sweat glands. It is of note that some of the preganglionic fibers enter the ganglion without a synapse and end in ganglia which are located at some distance from their origin. Thus the greater and lesser splanchnic nerves are so formed from preganglionic fibers. The greater splanchnic nerve arises from axons of the fifth to the tenth thoracic ganglia, the lesser splanchnic arises from the ninth to the eleventh, and the least splanchnic from the twelfth. These nerves end at the celiac, the aorticorenal and the renal plexuses, just beneath the diaphragm. The cervical sympathetic ganglia supply postganglionic fibers to form the cardiac nerves. There are also important sympathetic fibers which supply the bronchi and the abdominal viscera through distant ganglia such as the celiac and the mesenteric.

The parasympathetic portion distributes its connections differently from the sympathetic inasmuch as the axons from the cells of origin reach ganglia for synapse within the wall of the organ which they innervate. Parasympa-

thetic activity is also distinguished from that of the sympathetic by the fact that the former influences visceral rather than somatic activity. Important parasympathetic structures include the vagus nerve which disperses fibers through thoracic and abdominal organs, reaching two plexuses which have been termed "prevertebral" ones. The pelvic nerve, also identified as the nervus erigens, supplies the pelvic viscera, including genitalia, being distributed by the hypogastric plexus. The third, seventh, ninth and tenth cranial nerves supply fibers in the cranial portion of this system.

There are four paired autonomic ganglia within the head, each ganglion distributing both sympathetic and parasympathetic fibers. These include the ciliary ganglion within the orbit, the sphenopalatine ganglion in the pterygopalatine fossa, the otic ganglion distal to the foramen ovale in the infratemporal fossa, and the submaxillary ganglion on the medial aspect of the mandible.

Stated in general terms, many functions, a result of sympathetic and parasympathetic innervation, are antagonistic. Sympathetic influences are characterized by involving the entire body economy; whereas, parasympathetic activity is a more localized or restricted effect upon a single organ. Where one system is inhibiting the other system may be stimulating. Similarly, drugs have specific and antagonistic effects on either system. Atropine is stated to paralyze the parasympathetic while pilocarpine stimulates this system. Similarly, adrenalin or sympathin has a specific activity on the sympathetic system, while acetylcholine similarly serves the parasympathetic.

With the exception of vagotomy in the treatment of gastric ulcer, surgical methods deal mainly with the sympathetic portion of the autonomic nervous system. Thus, modern surgical procedures include resections of portions of the sympathetic chain in the treatment of hypertension and peripheral vascular disease. In the treatment of hypertension, a portion of the splanchnic nerves, the celiac ganglion, and a chain of ganglia are removed. Periarterial sympathectomy, denervation of the carotid sinus and the heart have also been used Dysmenorrhea has been surgically treated by interruption of the presacral nerves. Causalgia has also been treated by appropriate resection of the sympathetic nervous system. The pain of pancreatitis has more recently been relieved by removal of sympathetic influences which include afferent pain pathways.

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## *Ribs*

There are certain common characteristics of all ribs: Each has a vertebral part and a sternal portion. In between the two is the body or the shaft. The vertebral or posterior part of a rib is made up of the head, neck and tubercle. The head has an articular surface, usually divided into two, which articulates with the demifacets of the two vertebral bodies, adjacent to each other. The neck extends laterally from the head. It is

about an inch long. Immediately lateral to the neck is the tubercle which consists of an articular and nonarticular portion. The articular portion of the tubercle articulates with the tip of the transverse process at the lower of the two vertebrae to which the head of the rib is attached. The angle of the rib is the area of attachment of the sacrospinalis group of muscles on the convex surface of the rib and it is somewhat lateral to the tubercle. It is characterized by the presence of a prominent line directed downward and outward. The costal groove is along the inferior border of the rib and it houses the intercostal vessels and nerves.

The 10th, 11th and 12th ribs have a single articular facet on the head of the rib, and these ribs articulate with the corresponding dorsal vertebrae. The 11th and 12th ribs *have no neck or tubercle. They do not* articulate with the tip of the transverse process of the vertebra below. The 12th rib, in some instances, is rudimentary and very short.

### *Intercostal Arteries*

*There are nine pairs of intercostal arteries arising from the aorta.* They are distributed in the lower nine intercostal spaces. The upper two intercostal spaces are supplied by branches from the highest intercostal artery which is given off by the costocervical trunk of the subclavian artery. The intercostal arteries on the right side are longer than those on the left side because the aorta is in a position to the left of the midline in front of the vertebral column. The intercostal vessels pass behind the esophagus, the thoracic duct and azygos vein. They also pass behind the sympathetic trunk to enter the costal groove of a rib The artery is between the intercostal nerve and the intercostal vein. The relationship from above downward is vein, artery and nerve. Just as the artery enters the intercostal groove, it divides into its anterior and posterior branches. The anterior branch extends in company with the nerve and vein in the costal groove. The posterior branch courses between the body of the vertebra and rib, and after giving its lateral spinal branch, supplies the sacrospinalis group of muscles and the vertebral bony structure. It terminates in a medial and lateral terminal branch which supply the musculature as well as the skin and subcutaneous tissue.

The anterior branch of the intercostal artery is found between the internal and external intercostal muscles, beyond the angle of the ribs. Near the costal cartilages, these vessels anastomose with the intercostal branches of the internal mammary.

The intercostal arteries may be encountered in thoraco-lumbar sympathectomies in a position posterior to the sympathetic chain. At times, they are severed and they cause severe bleeding. Usually, electrocoagulation is necessary to stop such bleeding. The 2nd and 3rd intercostal arteries are encountered in upper dorsal sympathectomy and bleeding from these is managed easily

# General Surgical Management

CANDIDATES for surgical treatment designed to remove portions of the sympathetic nervous system are treated after medical consultation. The treatment of angina pectoris or hypertension requires careful and complete cardiac and renal studies. The treatment of peripheral vascular disease can be most effectively selected only after clinical studies have been performed in evaluating the status of the patient's preoperative responses to standardized testing. A careful selection of candidates for these various procedures may then result in more satisfactory outcome, and may eliminate unnecessary operations.

The selection of the anesthesia may be best left to the judgment of the anesthetist. In our experience, general intratracheal anesthesia has been used almost routinely in sympathectomy for hypertension, thus allowing inflation of the lung if the pleura is torn. Spinal anesthesia has been quite satisfactory in lumbar and sacral sympathetic resections. Occasionally, local anesthesia may be used. It has been our custom to carry out bilateral operations in two stages.

Sympathetic surgery may be performed for vasospastic disease of the extremities, for causalgia, for cardiac pain, to abolish sudomotor activity in certain parts of the body, and also to help decrease the spasm of vessels in the cranial cavity.

Vasospastic disease, in the upper extremities, such as Raynaud's disease, is best treated by a preganglionic type of sympathectomy. This is the type of operation described in the accompanying text. With preganglionic sympathectomy, thermal, chemical and other physical stimuli upon the involuntary musculature of the blood vessels do not result in an increased response; whereas, with a postganglionic type of sympathectomy, there is increased reactivity of the involuntary musculature to various forms of stimulation. In the lower extremities, sympathectomy by excision of the 2nd, 3rd and 4th lumbar ganglia is essentially a preganglionic type of operation because the vasomotor fibers pass through the ganglia and supply postganglionic cells in the more distal portions of the body.

When a cervicodorsal sympathectomy is performed for anginal pains it is important to remember that the sensory fibers supplying the heart arise from the 1st to the 5th dorsal and fibers from the left side predominate. In some instances a sympathectomy on the left side with excision of the

1st to the 5th dorsal ganglia may be effective. In most cases the operation has to be performed bilaterally. Excision of the ganglia in this operation is adequate.

The abolishment of sudomotor activity in the upper or lower extremities may be desirable in some patients. Excision of the 2nd and 3rd dorsal ganglia effectively stops sudomotor activity in the upper extremities and the face. Excision of the 2nd, 3rd and 4th lumbar ganglia results in sudomotor paralysis in the lower extremities. The operation is usually done by excision of the ganglia.

It has been fairly well established that the vasomotor activity in the upper extremities is mediated through the 2nd, possibly also the 3rd dorsal ganglia so that a preganglionic form of operation upon these two ganglia results in a good response and is not associated with a Horner's syndrome.

In recent years there has been interest in measures to enhance the blood flow and increase the blood supply of the brain. Though it is still in an experimental state, the evidence suggests that excision of the stellate ganglion bilaterally results in some increased blood flow through the brain. Stellate excision will result in a Horner's syndrome, but when this is done bilaterally the appearance of the patient is not particularly unusual. The patient also complain of a dry nostril. In many instances, excision of the stellate ganglion also destroys the vasomotor and sudomotor fibers of the upper extremities by destroying postganglionic fibers which mediate these functions in the upper extremities.

In doing a cervicodorsal sympathectomy, excision of a portion of the 3rd rib is adequate and this permits the exposure of the 2nd and 3rd intercostal nerves and the gray and white rami communicantes. If it is necessary to remove four or five ganglia for denervation of the heart, excision of a portion of the 2nd and the 4th ribs gives excellent exposure to the desired level.

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### *Sternocleidomastoid Muscle*

The sternocleidomastoid muscle superiorly is attached to the mastoid process and the lateral third of the superior nuchal line. Inferiorly, it is attached to the manubrium sterni and the medial third of the clavicle. These attachments are also called the medial or sternal head and the lateral or the clavicular head respectively. The sternocleidomastoid muscle through its lower two-thirds covers the carotid sheath containing the internal jugular vein, the carotid vessels and the vagus nerve. In operations upon the carotid sheath structures, the sternocleidomastoid is usually retracted posteriorly for exposure of these vessels. The sternocleidomastoid draws the head toward the shoulder on the same side and at the same time it rotates the head to the opposite side. With the two muscles working simultaneously the cervical spine may become flexed anteriorly, or if the head is fixed, the thorax may be pulled somewhat upward such as in forced inspiration.

# Neurosurgical Procedures

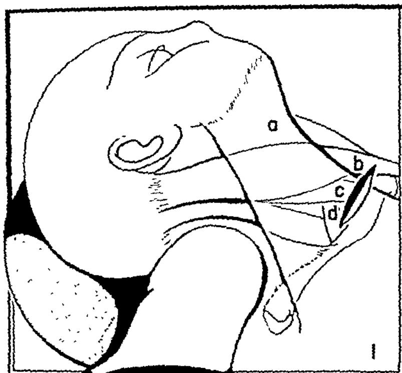
## Stellate ganglion excision

The position of the head is shown in *1*. The head is hyperextended and turned away from the side of operation over an appropriate support, such as a rolled sheet, or a sandbag. Before positioning the patient, particularly if the operation is to be performed bilaterally, the outline of the incision should be lightly scratched with the patient in the supine position. Both sides should be marked at the same time. The incision should extend laterally from the medial border of the sternocleidomastoid for *2* to *2½* inches just above the clavicle. If the medial half of the sternal head of the sternocleidomastoid is saved the contour of the neck is not disturbed. In some cases the operation may be completed without cutting the sternocleidomastoid muscle, but by retracting it medially.

The various muscles of the neck which are encountered in this procedure are shown in *1*: *a* is the platysma, *b* and *c* the medial and lateral heads of the sternocleidomastoid, *d* omohyoid. The incision extends from *b* to *d*.

In *2* the lateral head of sternocleidomastoid is being cut. This muscle should be exposed so that both the anterior and posterior surfaces of it are well visualized. As stated above, the lateral head in some cases may not have to be cut to expose the anterior scalene muscle. However, when cut, it can always be sutured. The dotted line shows the extent of the incision of the sternocleidomastoid. The medial half of the sternal head is saved. At *b* the scissors are used for blunt dissection of the areolar tissue overlying the anterior scalene muscle which can be felt with ease with the tip of the index finger This may direct the dissection over the muscle.

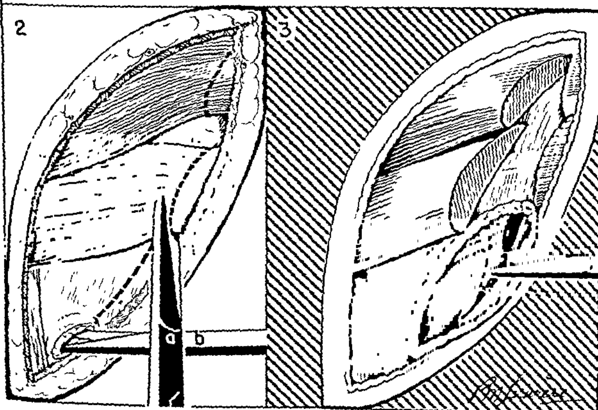
In *3* the anterior scalene muscle has been exposed in part. In some cases the lower end of the anterior scalene may be traversed by arteries and veins. Most of the time these may be retracted laterally or medially as their course may indicate On the other hand, at times, some branches of the suprascapular vessels may have to be doubly ligated and cut as is shown in *3*. The phrenic nerve is seen traversing the anterior aspect of the muscle along its medial border.




1a. Platysma.
b. Medial head of sternocleidomastoid.
c. Lateral head.
d. Omohyoid.
b to d. Incision for exposure of stellate ganglion.

2a. Scissors cutting lateral head of sternocleidomastoid Dotted line indicating extent of the cut involving lateral and medial heads.
b Scissors dissecting away areolar tissue overlying the anterior scalene muscle.

3. Anterior scalene exposed, suprascapular artery and vein doubly ligated and cut.





In *4* the phrenic nerve is being dissected free, as shown at *a*. After it is dissected free it is moved medially and it usually remains out of sight without undue traction. At *b* the anterior scalene is being cut. Before this is done both the medial and the lateral borders of the anterior scalene should be carefully exposed, and the posterior aspect of the muscle should be dissected free until an index finger may be passed under the muscle with ease. At times such a maneuver may cause bleeding from the branches of the thyrocervical trunk. After the muscle has been mobilized, either with a knife or scissors, the muscle can be bisected. Only a few bleeding points are encountered on section of the muscle, and some of the larger ones may be cauterized by the electric current. On cutting the muscle the ends retract, particularly because of the position of the head. The exposure of the underlying structures may be carried out without the necessity of retracting the muscle itself.

In *5* the exposure of the subclavian artery is carried out by blunt dissection of the fascia and the fat overlying the structure. Ordinarily there is very little fascial and areolar tissue covering the artery, and as soon as the muscle has been bisected the artery comes into view. With great care the artery is now separated from the surrounding tissues and certain branches are identified.

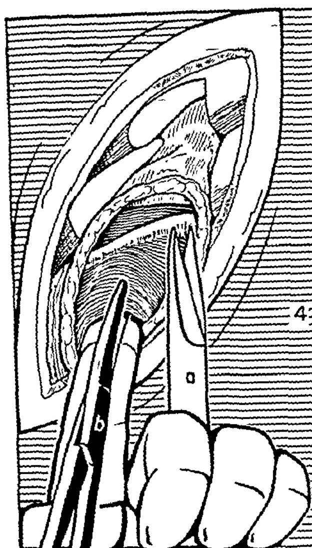
In *6* the subclavian artery is shown after having been dissected out. At *a* one sees the vertebral artery; at *b* the thyrocervical trunk; at *c* the mammary artery which is not usually seen in most dissections. Occasionally there may be an accessory cervical artery immediately lateral to the thyrocervical trunk. If this is present both it and the thyrocervical trunk have to be doubly ligated and cut.

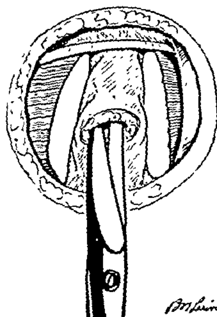
At *7* the subclavian artery is retracted with a lighted retractor showing the connective tissue over the 7th cervical transverse process, the dome of the lung, and pleural sac (Sibson's fascia). The next step is to expose the vertebral bodies at their junction with the transverse processes and ribs in order to visualize the sympathetic trunk. The stellate ganglion lies on the 7th cervical transverse process at the point of its junction with the body of the 7th cervical vertebra.

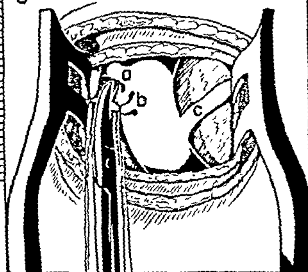
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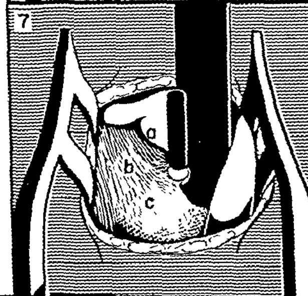
*The Phrenic Nerve or the Internal Respiratory Nerve of Bell*

The phrenic nerve or the internal respiratory nerve of Bell is both a sensory and motor nerve. It arises mainly from the fourth cervical nerve but it also receives twigs from the third and the fifth. It extends down on the anterior aspect of scalene muscle, it crosses the transverse *cervical and transverse scapular vessels and* passes in front of the subclavian artery between it and the subclavian vein and it enters the thorax. From the thorax it goes down in front of the root of the lung to the diaphragm to supply it with motor and sensory fibers.




4a. Phrenic nerve dissected.
b Cutting anterior scalene.
5. Exposure of subclavian artery by blunt dissection of fascia and fat under scalene.
6a. Vertebral artery.
b. Thyrocervical trunk doubly ligated and cut.
c. Mammary artery.
All branches of subclavian.
7a. Subclavian artery retracted.
b Sibson's fascia and
c. Dome of lung covered with pleura.

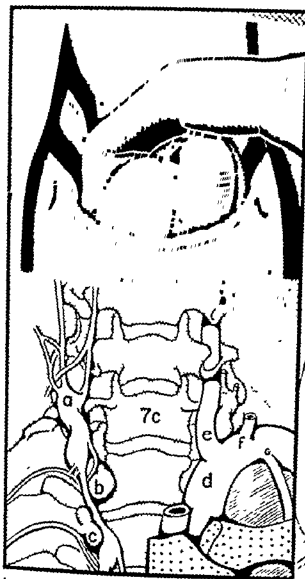
At *8* the use of the finger for exposing this region is now shown. Keeping the tip of the finger against bony structures the Sibson's fascia is carefully separated from these bony structures. By staying next to these bony structures the retropleural space is slowly entered. In *8* the pleural dome and the artery are shown immediately behind the index finger. In *9* the position of the sympathetic chain, in relation to the bony structures, is shown. At *a* the stellate ganglion overlying the transverse process of the 7th cervical is seen. In this region it is to be noted that the sympathetic chain is lateral to the head of the 1st rib, *b*. Lower down it occupies a medial position to the head of the 2nd and 3rd ribs, *c*. The head of the 1st rib can be very easily felt as a protrusion with the exploring fingertip. Lateral to this structure the sympathetic chain may be palpated or visualized. It is important to see these structures before cutting, because of the presence of venous channels, and on the left side, of the thoracic duct and its tributaries. In *9* at *d* is the subclavian artery on the left with its vertebral, thyrocervical and mammary branches showing. In *10* the stellate ganglion is shown at *b*. It can be visualized, and the dissection can be easily extended to the 2nd and 3rd dorsal ganglia by this approach. In *11* the stellate ganglion has already been partially excised and it is being cut at *b*, after placing a clip immediately below this point.

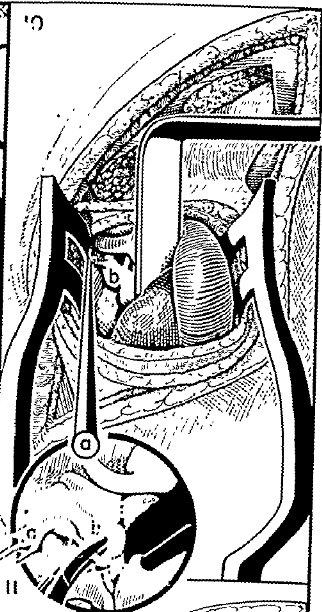
Stellate ganglion excision may be worthwhile in retinitis pigmentosa, in certain cerebral conditions deserving increased blood flow by dilation of cerebral vasculature. This type of sympathectomy may also be used in patients with hyperhidrosis of the upper limbs and axillae. In the latter cases the 1st, 2nd and 3rd thoracic ganglia should be excised.

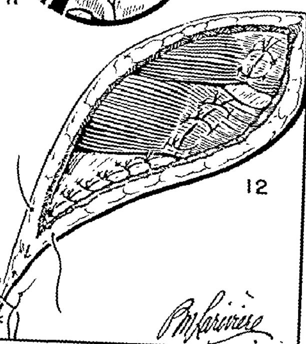
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### *The Subclavian Artery*

The subclavian artery is a branch of the innominate artery on the right side. On the left side, it arises from the arch of the aorta. The right subclavian artery is given off the innominate artery immediately behind the right sternoclavicular articulation. It extends upward and laterally, and passes posterior to the anterior scalene muscle and then extends laterally and downward to become the axillary artery. On the left side, the subclavian arises from the arch of the aorta in a position behind the left common carotid artery, it extends upward and when it reaches the lower end of the neck, it arches laterally behind the anterior scalene muscle, thence laterally and downward to become the axillary artery. The subclavian artery is separated from the subclavian vein by the anterior scalene muscle. In some instances, the vein may be posterior to the scalene muscle in company with the artery. Branches of the subclavian include the vertebral, the thyrocervical trunk, the internal mammary and the costocervical trunk.




8 Finger dissecting Sibson's fascia off vertebral column and posterior body wall

9a Stellate ganglion lying on transverse process of 7th cervical

b Head of 1st rib

c Head of 2nd rib

d Subclavian of opposite side

e Vertebral

f Thyrocervical

g Mammary

10 Retraction of pleura

a Hook on nerve leading to stellate ganglion

b Stellate ganglion

11a Stellate being excised

b Silver clip has been placed

12 Closure by interrupted silk

In certain diseases, characterized by vasospasm in the upper extremities, a preganglionic type of sympathectomy involving the 2nd and 3rd dorsal ganglia may be desirable and may be superior to ganglionectomy. The operation to be described is that of Smithwick and closely follows his technique.

In *1* the position of the patient and the position of the incision are shown. The patient is in the prone position with the chest above the level of the head and with the head rotated toward the operated side. The incision extends from the level of the 1st dorsal spinous process downward and outward for three inches and is intended to expose the 3rd rib and its junction with the 3rd dorsal vertebra. The body may be positioned in such a way that the shoulder will fall forward on the operated side and the head will be flexed.

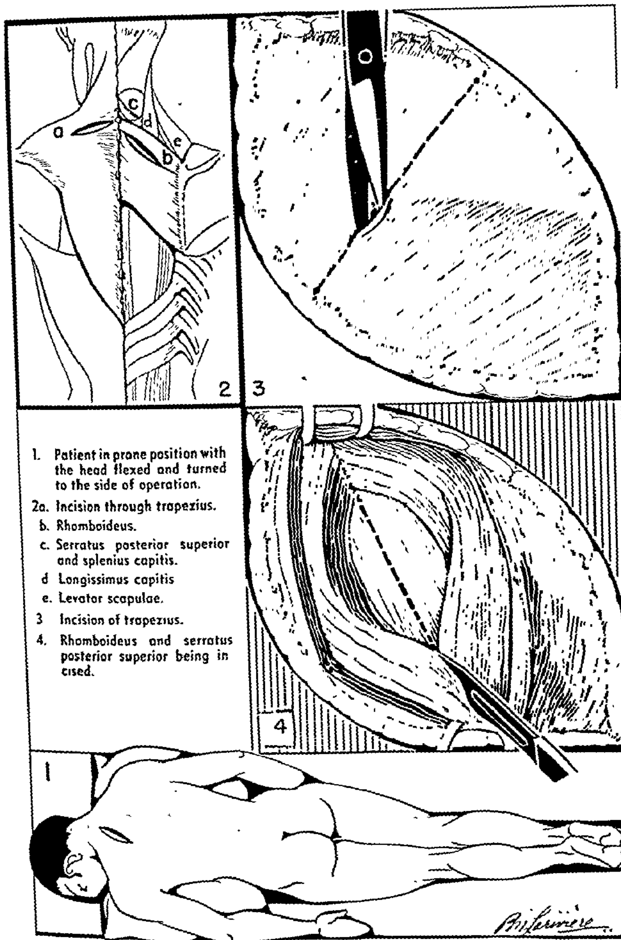
In *2* the anatomy of the various muscles of the back is given in a diagrammatic style. In *a* the trapezius muscle and its incision; at *b*, the rhomboideus and its incision are shown. At *c* one sees the serratus posterior superior, and just a little above same, the splenius capitis, at *d*, a little lateral to it, at *e*, the longissimus cervicis and capitis muscles. The levator scapulae may be seen at *e* extending upward and medially.

In *3* the skin incision has been made and the trapezius muscle is being incised. *In muscular individuals it may be preferable to cut the trapezius* muscle. In *4* the trapezius incision and the incision through the rhomboideus have been completed, and the dotted line shows the incision through the serratus posterior superior. The artery to the trapezius, on the deep surface of the muscle, may be cut. This is a branch of the transverse cervical artery. Perforating branches of the upper intercostals may be encountered when the rhomboideus and the serratus are incised. When this is done the 3rd rib can be exposed. *The position of the 2nd and 3rd ribs should be ascertained* accurately.

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*The Omohyoid Muscle*

The omohyoid muscle is made up of two muscular bellies united by an intervening tendinous portion. Inferiorly, it is attached to the upper border of the scapula, passing behind the sternocleidomastoid muscle, it extends upward at an obtuse angle The superior belly which extends vertically upward is attached to the lower border of the hyoid bone This muscle is frequently seen in dissections of the neck and its resection or excision may be necessary in some of these dissections Usually, one is able to dissect it away from the area of the operation. The lower belly is attached by a fibrous band to the upper border of the clavicle and courses medially and slightly upward until it reaches the posterior aspect of the sternocleidomastoid muscle.




1. Patient in prone position with the head flexed and turned to the side of operation.

2a. Incision through trapezius.
b. Rhomboideus.
c. Serratus posterior superior and splenius capitis.
d Longissimus capitis
e. Levator scapulae.

3 Incision of trapezius.

4. Rhomboideus and serratus posterior superior being in cised.

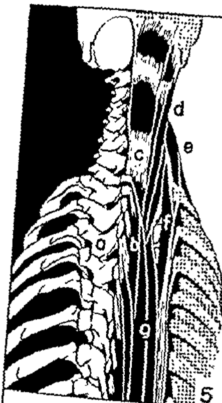
In 5 one sees the thoracic cage on the one side and the muscles of the back on the other. At *a* one can see the 3rd dorsal vertebra and its junction with the 3rd rib. The spinous process tips of the 1st, 2nd and 3rd dorsal vertebrae are in line with the 1st, 2nd and 3rd ribs respectively. A good exposure of the transverse process of the 3rd rib should be made in this operation. The longissimus dorsi is seen at *b*; *c* is the semispinalis capitis; *d* is the longissimus cervicis and capitis; while *e* is the posterior scalene muscle attached to the 1st rib posteriorly; *f* is the iliocostalis cervicis and dorsi; *g* is the longissimus dorsi. In exposing the transverse process of the 3rd rib, it may be necessary to cut some of the fibers of the longissimus dorsi transversely. Some of the fibers of the iliocostalis dorsi also have to be cut transversely in order to expose the junction of the rib with the transverse process.

In 6 the transverse process of the 3rd dorsal vertebra and the 3rd rib have been exposed. This may necessitate cutting transversely the deeper fibers of the longissimus cervicis. Dorsal branches of the upper three intercostal arteries may be encountered in the dissection. They should be controlled by electrocoagulation. At *a* a subperiosteal exposure of the 3rd rib is performed. At *b* the transverse process of the 3rd dorsal vertebra is being rongeured away, thus exposing the neck of the 3rd rib. One now carefully separates the rib from its bed by using a rib elevator with semi-circular tip as shown at *c* in 7. The pleura should not be torn because the operation becomes somewhat more complicated with air being sucked in and expelled with respirations. The rib now is cut for a matter of 2 to 3 inches beyond the junction of the neck and the tubercle. Most of the neck of the rib should also be removed. It is important to be careful and retract the pleural lining so as not to traumatize it before cutting the rib.

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### *The Subclavian Vein*

The subclavian vein is the upward extension of the axillary vein and extends from the outer border of the 1st rib to the medial end of the clavicle. *It unites with the internal jugular to form the innominate vein.* The subclavian vein is immediately behind the clavicle and the subclavius muscle, and above it and immediately posterior to it is the subclavian artery from which in most instances it is separated by the anterior scalene muscle and the phrenic nerve. Inferiorly, it rests on the 1st rib and the pleural lining. The subclavian vein usually receives the *external jugular vein. On the left side, at the junction of the* internal jugular and the subclavian veins is the entrance of the thoracic duct. The left innominate is twice as long as the right innominate vein and is formed by the confluence of the internal jugular and the subclavian veins. The left innominate extends obliquely downward and medially behind the manubrium sterni and unites with the right innominate vein *behind the right first costal cartilage.* These two veins now form the superior vena cava which empties into the right atrium.




5a. 3rd dorsal
b. Longissimus dorsi.
c. Semispinalis capitis.
d. Longissimus cervicis and capitis.
e. Posterior scalene.
f. Iliocostalis cervicis and dorsi
g. Sacrospinalis or longissimus dorsi

6. 3rd rib exposed
a. Periosteum scraped off 3rd rib and 3rd dorsal transverse process.
b. Rongeuring away transverse process of 3rd dorsal.

7a. Neck of 3rd rib being removed
b. Rib cutter
c. Rib is freed from its bed

In *13* the sympathetic chain is cut between the 3rd and 4th dorsal ganglia and the two intercostal nerves are separated. The 2nd and 3rd ganglia are now mobilized. The cut end of the ganglionated chain is now enclosed in a tantalum cuff, or a tube of rubber or polyethylene, as shown in *15* at *a*. The cuff is ligated around the chain superior at *14a* and at the tip *14b*. The cuff and its contents are then sutured to the back muscles on the outside of the thoracic cage as shown in *15a*.

In *12* the extent of the sympathectomy is shown with the 2nd and 3rd intercostal nerves excised at the anterior and posterior roots. The sympathetic chain is then separated between the 3rd and 4th ganglia. After clipping off the 2nd and 3rd intercostal nerves the chain is sutured to the muscles outside the thoracic cage in a tube of rubber or polyethylene, or a tantalum cuff which is made by surrounding the ganglia of the chain with a sheet of tantalum. In *a* ganglionated chain, *b* dorsal ganglion, anterior and posterior spinal nerve roots, *c* spinal cord are shown. The shaded area is the portion separated from spinal cord and sympathetic chain.

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### *The Anterior and Middle Scalene Muscles*

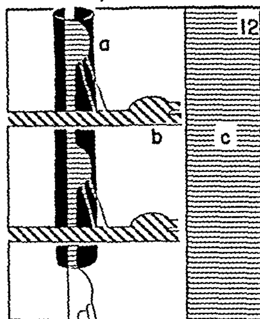
The anterior scalene muscle is attached to the scalene tubercle of the 1st rib, immediately in front of the subclavian groove and the subclavian artery. With its attachment to the 1st rib, it separates the subclavian artery and the subclavian vein. The latter is in front of the muscle attachment Superiorly, the anterior scalene muscle arises from the transverse processes of the 3rd, 4th, 5th and 6th cervical vertebrae. The brachial cords forming the brachial plexus pass immediately posterior to the anterior scalene muscle, between it and the middle scalene muscle.

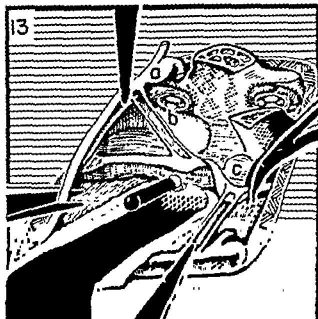
The middle scalene muscle arises from the transverse processes of the lower six cervical vertebrae and becomes attached to the 1st rib posterior to the subclavian groove. The subclavian artery passes between the middle and anterior scalene muscle.

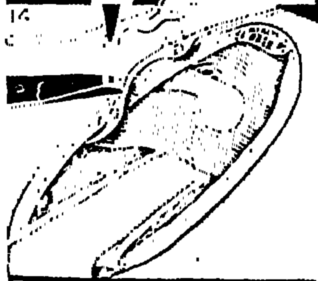
### *Cervical Sympathetic Chain*

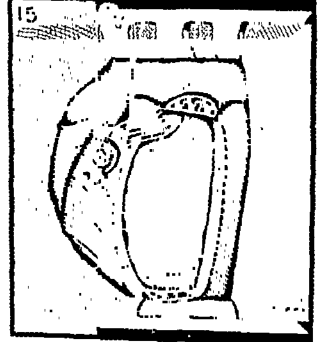
The cervical sympathetic chain consists of the superior, middle, and inferior cervical ganglia, connected by intervening nerves The preganglionic fibers to these cervical ganglia arise from the upper thoracic spinal nerves. The superior cervical ganglion is in a position posterior to the internal carotid artery and internal jugular vein and in front of the prevertebral fascia and the longus capitus muscle. It is of grayish color and fusiform, broad and flat, and it gives off several branches, including the nerve to the internal carotid artery, branches to the various cervical nerves, the superior cardiac, lingual and the pharyngeal branches.

The middle cervical ganglion is very small. It gives off the middle cardiac nerve. The inferior cervical ganglion is found at the junction of the transverse process of the 7th cervical and the neck of the first rib It is frequently fused with the 1st thoracic ganglion, to form the stellate ganglion It gives off the inferior cardiac nerves, and branches to blood vessels






12. Diagram of extent of sympathectomy.
    2nd and 3rd ganglia denervated and cut.
    a. 2nd and 3rd ganglia are shown.
    b. 2nd and 3rd intercostal nerves and roots.
    c. Spinal cord.

13a Cutting 2nd intercostal nerve.
  b. Cut ends of anterior and posterior roots.
  c. Cutting sympathetic chain.

14a, b. 2nd and 3rd dorsal ganglia. The 2nd intercostal nerve trimmed away from sympathetic chain.

15 Suturing of sleeve to intercostal muscles.

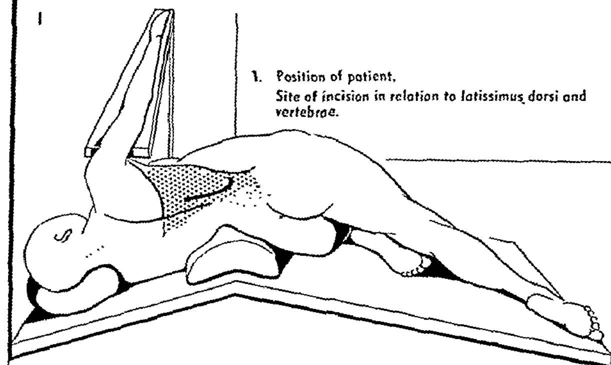
Thoracolumbar sympathectomy is mainly used for hypertensive disease, but recently it has also been employed with encouraging results in patients with intractable pain from chronic pancreatitis.

*The Evolution of Thoracolumbar Sympathectomy.* In 1927 an Italian surgeon, Pieri, suggested the use of splanchnicectomy for hypertensive disease. The operative approach to the problem was crudely worked out. In 1928 through 1934, Adson and his associates studied hypertensive disease in relation to results from section of the anterior roots of thoracic spinal nerves, which also included section of the sympathetic fibers. Later Craig and Brown described their infradiaphragmatic lumbar sympathectomy in the management of some patients with hypertensive disease. In 1934, Peet described a method of supradiaphragmatic approach to the thoracic sympathetic chain and the splanchnic nerves. In 1939, and 1940, Smithwick and White described their modification of the sympathectomy in that they combined both the infra- and supradiaphragmatic approaches in a single operation. The present operative approach to be described is a slight modification of the Smithwick technique as used in our clinic.

*1.* The position of the patient is of the utmost importance for the proper performance of the operation. With the patient on his side the lower extremity next to the table is placed in a flexed position, while the other one is completely extended. The lower thoracic and abdominal areas are placed in some degree of lateral extension by appropriate breaking of the table. Such positioning is particularly important if the patient is short and stocky. A stand is generally used to support the upper extremity away from the table for intravenous fluids and other medication, while the upper extremity next to the table may be used for application of the blood pressure cuff. Intratracheal anesthesia is preferred to control respirations.

In *1* the position of the patient is shown and the site of the incision, in relation to the latissimus dorsi and vertebrae, is outlined. The incision extends from about the level of the 10th dorsal vertebra, two inches lateral to the midline, curving downward and outward just below the 12th rib The entire incision is usually about six to seven inches long. The lower end of it is in a plane just posterior to the anterior-superior iliac spine.

In *2* the skin has been incised and the scissors are cutting the latissimus dorsi and a portion of the posterior inferior serratus, which may be muscular or tendinous, depending upon how near the midline the incision may be, and also depending upon variations from patient to patient. As soon as the incision has been made, exposing the erector spinae, the index finger may be used to undermine the sheet of muscle inferiorly and superiorly, the line of division being between these structures and the erector spinae group of muscles In many instances the latissimus dorsi and the serratus posterior inferior are reflected at the same time. After undermining these structures the scissors may be used for extension of the incision Several bleeding points may be encountered A rather constant one is a subcutaneous and muscular branch of the 11th or 12th intercostal artery




1. Position of patient.
Site of incision in relation to latissimus dorsi and vertebrae.

2. Skin incision extended through subcutaneous fat.
Scissors cutting latissimus dorsi

2

In *1* the various muscles encountered in this operation are shown. The trapezius and latissimus dorsi of the opposite side are at *a* and *b* respectively. The serratus posterior inferior is *c*, *d* is external oblique, *e* is internal oblique and *f* is the erector spinae. It should be pointed out that on incising the latissimus dorsi, one also incises the tendinous portion of the serratus posterior inferior, and this muscle, as well as the latissimus dorsi, are reflected laterally together. The attachments of the serratus posterior inferior to the ribs may be seen on the internal surface of the reflected sheet of muscular tissue.

After incision of the latissimus dorsi, the muscle is reflected upward and laterally, thus exposing the erector spinae and the attachments of the serratus posterior inferior. With care the erector spinae is reflected and retracted posteriorly and some of the attachments of the serratus posterior inferior and the erector spinae are cut off the 12th and 11th ribs. The 12th rib is now exposed from its attachment to the body of the vertebra for a distance of about 4 to 5 inches. In certain instances, the 12th rib may be rudimentary and short. One may either elect to remove the 11th rib in such a case, or both the 11th and 12th ribs together. In some, good exposure has been obtained by removing this rudimentary 12th rib and entering the retropleural space in the usual manner.

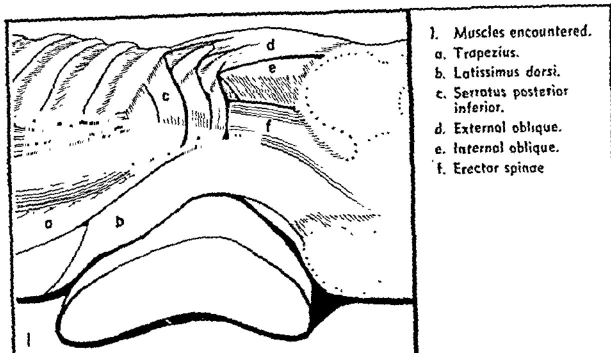
In *2* the following are shown: At *a* the reflected edge of the latissimus dorsi and serratus posterior inferior; at *b* cutting of the attachments of the erector spinae to the lower and posterior aspect of the 11th rib; at *c* the exposure of the 12th rib by a subperiosteal dissection.

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### *The Kidney*

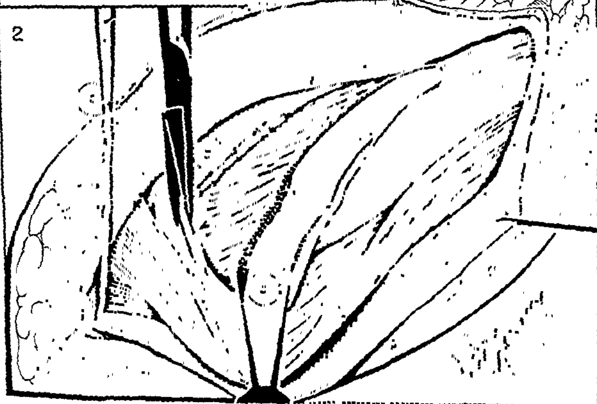
Each kidney is about 11 cms by 5 cms by 2½ cm The left is somewhat longer and narrower than the right. Each kidney weighs in the neighborhood of about 135 grams It is a firm structure and is reddish brown in color In doing thoracolumbar sympathectomies, the colors of these various structures are characteristic. The suprarenal gland is a definite yellow. The kidney is a reddish brown covered with a capsule. The spleen is a dark purple, also covered with a capsule and the pancreas is a brownish gray fibrous structure and is not covered with a distinct capsule.

Posteriorly, the kidney is in relation with the diaphragm, the transversus abdominis, the quadratus lumborum and the psoas muscle It is covered with the perirenal fat through which the kidney may be felt with ease on palpation. The fatty capsule of the kidney is in turn covered by the renal fascia which is a continuation of the subperitoneal fascia. The renal fascia surrounds the kidney both anteriorly and posteriorly, and extends across the midline over the large vessels and becomes continuous with the renal fascia on the other side The suprarenal gland is in a position anterior and medial to the upper pole of the kidney




1. Muscles encountered.
 a. Trapezius.
 b. Latissimus *dorsi*.
 c. Serratus posterior inferior.
 d. External oblique.
 e. Internal oblique.
 f. Erector spinae

2a. Hemostat holding latissimus *dorsi*.
 b. Scissors cutting *serratus* and attachments of erector spinae.
 c. Periosteal elevator removing periosteum *from 12th* rib.



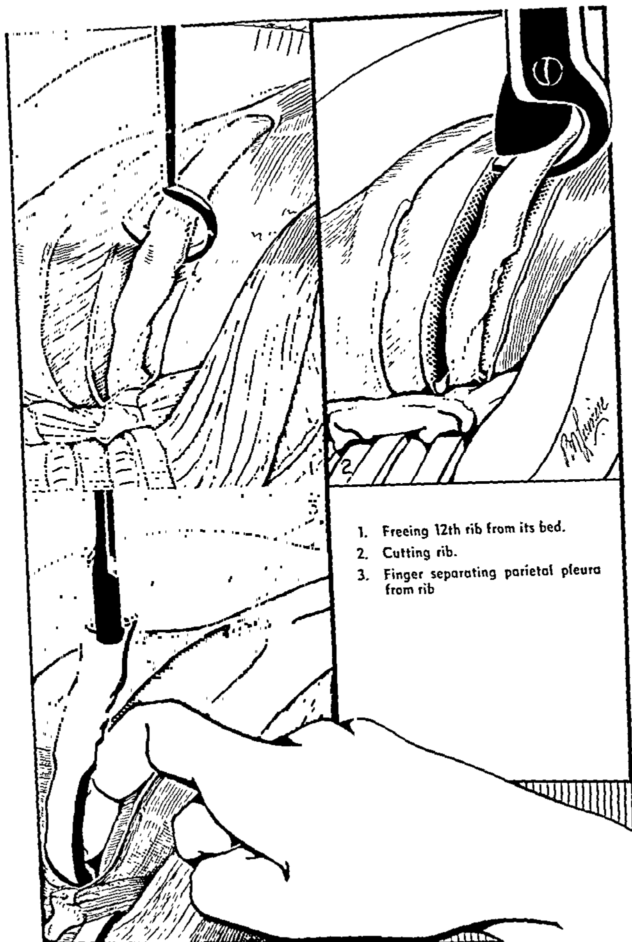
In *1* the 12th rib is separated from the periosteo-pleural shell. Before passing of the circular elevator around the rib, the periosteal covering of the rib is separated along the superior and inferior borders of the rib. When the superior border of the rib is dissected free the elevator can be carefully passed under the rib and the dissection extended until the inferior border is reached. The inferior border of the rib is now separated by sharp dissection with a knife immediately over the elevator which is passed downward under the rib. In exposing the inferior border of the rib it is important not to traumatize the intercostal nerve and vessels. When the inferior and superior borders of the rib have been separated the circular elevator is passed around the rib and with careful stroking upward and downward the periosteal stripping is extended. It is important to retract the erector spinae group of muscles to expose the junction of the rib and the transverse process of the 12th dorsal vertebra. The transverse process of the 1st lumbar vertebra and the 11th dorsal can also be adequately exposed. Scissors may be advantageously used in freeing the 12th rib from its muscular attachments.

In *2* the rib has been separated from the periosteo-pleural covering all the way from the transverse process of the 12th dorsal vertebra for a distance of 4 to 5 inches. The rib is now cut laterally. In certain instances the rib may not be as long as shown in the illustrated dissection. Under those circumstances it can be separated completely from its attachments laterally and grasped in a bone forceps as shown in *3*. One of the most important maneuvers is shown in *3*—the separation of the periosteo-pleural covering from the inner surface of the rib at its junction with the body of the vertebra. Unless this part of the dissection is carried out in the proper plane, there is great likelihood of tearing the pleural lining. This is not necessarily a serious problem, but the operation is much cleaner and less complicated with the pleura intact.

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*Adrenal Gland*

The adrenal glands are found immediately above and in front of the upper end of each kidney. Above the right adrenal are found the liver and the inferior vena cava. Its posterior surface is upon the diaphragm above, and the anterior surface of the kidney below. The right adrenal is triangular in shape. The left adrenal gland is somewhat larger than the right and is semilunar in shape, with its concave aspect against the medial upper border of the left kidney, and its convex surface immediately against the left crus of the diaphragm. Anteriorly, the gland is in contact with the peritoneal lining of the omental bursa and the pancreas. Posteriorly, it rests against the kidney, as well as against the left crus of the diaphragm. The adrenals are yellowish in color. These structures are about 1 to 3 inches in length, and about 1 inch in width and about $\frac{1}{4}$ of an inch in thickness.




1. Freeing 12th rib from its bed.
2. Cutting rib.
3. Finger separating parietal pleura from rib

In *1* the excision of the rib is shown. This is extended all the way to the junction of the rib with the body of the vertebra and any bleeding points from the residual stump may be stopped with the use of bone wax. The end of the rib can be rounded with a rongeur to remove sharp points which might tear the operator's glove.

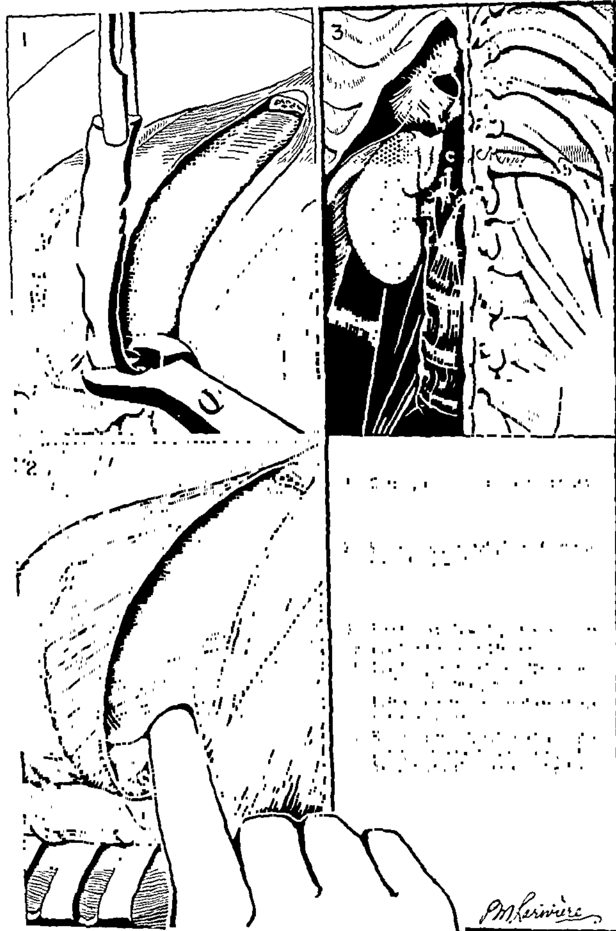
In *2* further dissection with the finger of the periosteo-pleural lining from the body wall is demonstrated. One dissects inferiorly toward the diaphragm, since this part of the dissection is much easier and less likely to cause a tear of the pleural lining. As the dissection proceeds one should look at the junction of the dissected and the residual adherent parietal pleural lining. The use of blunt scissors to continue with the dissection may be worthwhile at this juncture. Often it is a simple matter to extend the dissection all the way to the midline and then extend it superiorly as well as inferiorly in order to have adequate exposure for the excision of the sympathetic chain. If the pleural lining has been torn one bluntly dissects under direct vision until the pleural lining has been mobilized in the region of the tear. After packing the area of tear with wet gauze one continues the further dissection of the parietal pleural lining from the body wall.

In *3* the anatomic features of this region are shown, as seen both posteriorly and anteriorly. To the right one sees the right posterior body wall.

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*The Pancreas*

The pancreas may be encountered in thoracolumbar sympathectomy on the left side when the retroperitoneal space is entered. Only the body and the tail are encountered. The body of the gland, which is yellowish brownish in color and hard on palpation, is triangular in shape and has an anterior, posterior and inferior surface. It is about 15 cm. long, 3 to 4 cm. wide and about 2 cm. thick. The anterior surface is covered by the omental bursa and is in relation with the posterior aspect of the stomach. The posterior surface is in relation with the aorta, the splenic vein, the left kidney and the left adrenal gland. The inferior surface is covered with peritoneum and extends from the duodeno-jejunal flexure to the left colic flexure. The tail of the pancreas is narrow. It extends to the anteromedial surface of the spleen.


1
2
3

In *1* the sympathetic chain and splanchnic nerves are shown *after retraction* of the pleural lining from the body wall. The greater splanchnic nerve is usually seen with ease; on the other hand, in some patients, excessively obese in this region, it may be necessary to dissect the nerve from a fairly thick pad of adipose tissue. On the right side such a dissection is not fraught with much difficulty, but on the left side, one may injure the thoracic duct and its tributaries resulting in chylothorax. Only once have we seen a rather *large thoracic duct on the right side, the section of which resulted in the* escape of clear chylous fluid. If such a structure has been torn it is imperative to dissect it free and ligate it. The greater splanchnic nerve may be gently pulled so as to cause the celiac *ganglion to be drawn through the diaphragm.* This is easily accomplished, and after cautery of some of the vasculature in the vicinity with great care a portion of the celiac ganglion is excised. In some cases diaphragmatic fibers of the crura may have to be sectioned for proper exposure of the celiac. Clips may also be used for this purpose. After the celiac ganglion has been partially excised one now continues with exposure of the sympathetic chain. The 11th sympathetic *ganglion* is seen just above *the diaphragm. The 12th ganglion is found to be immediately* above, in or under the diaphragm and is easily visualized. To reach the 1st lumbar ganglion the medial few fibers immediately overlying the sympathetic chain are cut. By so doing one can extend the exposure inferiorly and dissect out the 1st lumbar ganglion. The lesser and least splanchnic nerves are dissected free. The lesser splanchnic nerve usually has to be cut above the diaphragm

In *2* the extent of the sympathectomy is shown. Usually, splanchnic nerves, a small portion of the celiac ganglion, and the 9th dorsal to the 1st lumbar chain included are excised. This can all be done by a supradiaphragmatic approach *facilitated by a short incision of the medial fibers of the* diaphragm near the sympathetic chain. These fibers need not be sutured

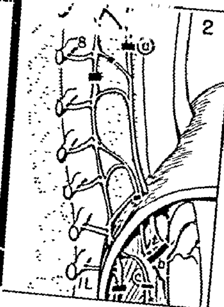
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*The Spleen*

The spleen is mainly encountered in sympathectomies when the kidney and the adrenal gland are exposed on the left side It is dark purple in color, weighs around 150 grams, is 12 cm in length, 7 in breadth, and 3 or 4 cm in thickness according to Gray's Anatomy It is in juxtaposition with the 9th, 10th and 11th ribs on the left side and externally, it is in contact with the diaphragm The anterior surface is in relation with the stomach and its inferior and posterior surface is in relation with the kidney on the left side and the left adrenal gland Inferiorly, it is also in relation with the transverse colon.

1

a




1a. Hook pulling on greater splanchnic nerve, delivering portion of celiac ganglion through diaphragm.
b Lesser splanchnic nerve.

2a. Greater splanchnic nerve.
b Greater splanchnic nerve
Lesser splanchnic nerve and celiac ganglion.
c. Least splanchnic nerve.

8 8th dorsal nerve.

1L 1st lumbor nerve.

In *1* the diaphragm is shown with the aortic and the esophageal apertures at *d* and the vena caval aperture at *c*. At *a* is shown the portion of the diaphragm that may need to be sectioned immediately overlying the sympathetic chain to reach the subdiaphragmatic portion of the sympathetic chain and the 1st lumbar ganglion. The incision is extended further to include the region from *a* to *b* in the Smithwick procedure which necessitates suture of the diaphragm, particularly its lateral portion. When only a few of the fibers immediately overlying the sympathetic chain have been cut it is not necessary to close this defect in the diaphragm.

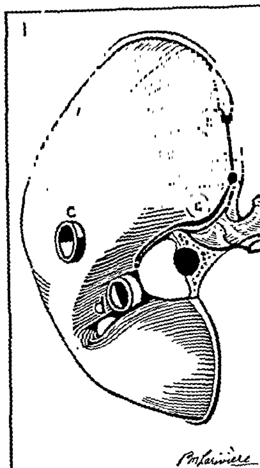
In *2* a portion of the diaphragm is being sectioned to expose the 1st and 2nd lumbar ganglia. The scissors are being used to cut this portion of the diaphragm. The operator occasionally will encounter small vessels which have to be coagulated, but ordinarily this region is quite avascular. The dissection is now extended inferior to the diaphragm and the 1st lumbar ganglion is exposed as shown in *3*. A clip may be applied to the distal portion of the sympathetic chain and its adjacent rami. The sympathetic chain is now carefully dissected away from its bed and the chain and the splanchnic nerves are reflected upward.

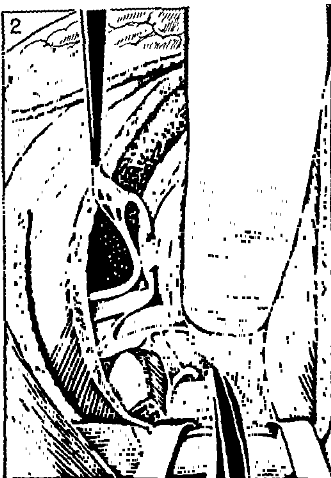
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### *Latissimus Dorsi Muscle and Lumbodorsal Fascia*

The latissimus dorsi muscle arises from the posterior layer of the lumbodorsal fascia and the sacral and lumbar spinous processes and the lower six thoracic spinous processes The more lateral fibers are attached to the crest of the ilium. Some fibers also arise from the lower three or four ribs These various fibers converge to form a thick bundle of muscle fibers, curving around the teres major muscle in the shoulder girdle. It ends in a tendonous sheath which becomes inserted into the intertubercular groove of the humerus in front of the teres major tendon. The latissimus dorsi can draw the humerus downward and backward, at the same time rotating it inward. Both muscles working together may help draw the trunk forward as in climbing.

The lumbo-dorsal fascia is a two-layer structure in the lumbar and sacral area. The posterior layer is attached to the spinous processes of the lumbar and sacral vertebrae, and the supraspinal ligament. The anterior layer arises from the transverse process of the lumbar vertebrae The two layers converge and unite, containing between them the sacrospinalis group of muscles. At the point of convergence, there forms a tendon of origin of the transverse abdominal muscle The lumbodorsal fascia is also intimately connected with the origin of the latissimus dorsi and the serratus posterior inferior muscles. It is a tough membrane and if a small area needs to be repaired or patched with a fascial lining, the lumbodorsal fascia can be used to advantage, particularly in the repair of defects in the dural lining from penetrating wounds of the spinal canal and spinal cord in the lumbar and the lower dorsal region




1. Diaphragm and apertures from above.
   *a. Incision near body of vertebra.*
   a, b. Incision for Smithwick procedure.
   c Inferior vena cava.
   d. Aorta and esophagus.

2. Incision of diaphragm and sympathetic chain

3. 1st lumbar ganglion exposed. This opening in diaphragm does not need closure.



In *1* the freed sympathetic chain and the splanchnic nerves are shown. This exposure of the chain to the 9th dorsal ganglion is made possible by blunt dissection of the pleura from the body wall until the latter is separated from the body wall at the level of the 8th and 9th ribs posteriorly. In exposure of this area it is important to cut the costovertebral ligament between the 11th rib and the vertebral bodies, without cutting the intercostal nerve and vessels. This will give an additional one-half inch of exposure. One can also use a Cushing subtemporal retractor to elevate the 11th rib and by careful retraction can visualize the sympathetic chain all the way up to the 9th ganglion. *In carrying out this dissection one occasionally injures an inter*costal vessel which may bleed profusely. Consequently, it is important to carry out the dissection under direct vision at all times, rather than by blunt and blind dissection. Long Frazier type of lighted retractors are most helpful. The use of silver clips at the point of section may be of value in preventing regeneration of nerve fibers.

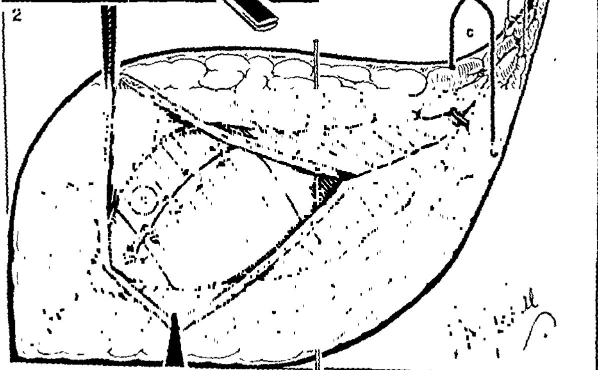
In *1* the azygos system of veins and the intercostal vessels are shown. There may result serious bleeding from rupture or tear of these vessels. Fortunately, the sympathetic nerves lie anterior to these structures and ordinarily there is no cause for concern if reasonable care is used.

After excision of the sympathetic chain all bleeding points are carefully controlled, usually by electrocautery. The anesthetist and the surgeon should exercise caution to avoid explosive accidents. If tear of the pleural lining has occurred this may be repaired. It is important to inflate the lung until it entirely fills the pleural cavity. This should be done under direct *vision so that there is no question about the possibility of pneumothorax.* Even when the pleura has been torn such inflation of the lung abolishes this postoperative complication. If the pleura has been torn there may be trapping of large amounts of air at a point inferior to the lung. If this air remains it *will* compress the *lung* and *keep it from becoming inflated properly* After complete inflation under direct vision there is no indication for drainage or the use of stout rubber tubes for creating negative pressure by suction in the pleural cavity While the lung is kept in an inflated state the cavity of the chest is closed as shown in *2a*. The lateral border of the erector spinae is sutured to the posterior inferior serratus along the rib margins. An air tight closure is thus obtained while forced respirations keep the lung inflated The latissimus dorsi is sutured as shown at *2b;* the skin and subcutaneous tissues are also approximated with interrupted silk sutures.




1a. Sympathetic chain and splanchnic nerve and portion of celiac before excision.
b. Iliocostalis.
c. Azygos system of veins and intercostal arteries and veins.

2. Closure.
a. Erector spinae and inferior serratus attachment sutured.
b. Closure of latissimus dorsi.
c. Subcutaneous closure.
d Skin closure.



## Additional Anatomical Descriptions Pertinent to Thoracolumbar and Lumbar Sympathectomy

### *Thoracolumbar Sympathetics*

The preganglionic fibers of the thoracolumbar sympathetics arise from the dorsolateral portion of the anterior column of the gray matter of the spinal cord in the thoracic and in the upper two or three lumbar segments. These fibers pass out with the anterior roots of all the thoracic nerves and the upper two or three lumbar nerves. After union of the anterior and posterior roots in the formation of spinal nerves these preganglionic fibers form the white rami communicantes and extend to the sympathetic chain. These fibers may end in the sympathetic ganglion first entered or they may extend upward and downward and terminate in other sympathetic ganglia higher or lower or they may continue as preganglionic fibers until they reach the wall of the organ in which are found post-ganglionic cell bodies and about which they terminate. The thoracolumbar sympathetics consist of the sympathetic chains which are found on either side of the midline in two vertical rows just lateral to the vertebral column. Collateral ganglia are found in front of the bodies of vertebrae and form the prevertebral plexuses in the posterior mediastinum, the abdominal cavity and pelvis and are the cardiac, solar and hypogastric plexuses respectively. In the thoracic region there are usually ten or eleven ganglia; in the lumbar area usually there are four. There are four or five ganglia in the sacral region and of course, there are three in the cervical portion. The ganglionated chains give off fibers which join the outgoing spinal nerves in the form of gray rami communicantes. White rami also arise from the second, third and fourth sacral nerves but these belong in the parasympathetic group.

The thoracic ganglionated chain rests upon the heads of the ribs. It is covered by the parietal pleura. The last two ganglia are on the side of the bodies of the eleventh and twelfth thoracic vertebra respectively. The first thoracic ganglion is large and is frequently blended with the inferior cervical ganglion to form the cervicothoracic or stellate ganglion. The visceral branches from the lower seven ganglia form the greater, lesser and least splanchnic nerves The least splanchnic nerve arises from the twelfth thoracic ganglion. It extends into the renal plexus. The lesser splanchnic nerve is formed by branches from the ninth, tenth and possibly also the eleventh thoracic ganglia. It supplies the aorticorenal ganglion and the celiac ganglion. The greater splanchnic nerve is formed by branches from the fifth to the ninth or tenth thoracic ganglia and possibly also from some fibers above this level, and it ends in the celiac ganglion

### *Diaphragm*

The thoracic and abdominal cavities are separated from each other by the diaphragm which is a musculo-fibrous septum It arises from the posterior aspect of the xiphoid process of the sternum, the inner surfaces of the lower six ribs on either side, from the lumbocostal arches and from the bodies of the upper two or three lumbar vertebrae. The latter constitute the two crurae The posterior portion of the diaphragm is of par-

ticular interest to the neurosurgeon in the sympathectomies. The *lateral* lumbodorsal arch, from which some of the fibers of the diaphragm arise, arches across the quadratus lumborum and is attached to the transverse process of the 1st lumbar vertebra and the lower margin of the 12th rib, all the way to its tip. The medial lumbocostal arch covers the upper part of the psoas major and it extends from the body of the 1st and 2nd lumbar vertebrae, to the anterior aspect of the transverse processes of these vertebrae.

The crurae are tendinous structures *arising from the bodies of the upper* two or three lumbar vertebrae. They give rise to muscular fibers which extend forward and join the central tendinous leaf of the diaphragm in such a manner that the aorta and esophagus are surrounded by the interlacing fibers from the two sides.

The muscular tissue of the diaphragm inserts itself into the central tendon which is made up of three portions, which include the right and left leaflet, and a middle portion. The pericardial sac is blended with the superior surface of the central tendon.

Openings in the diaphragm include the vena cava opening, the esophageal and the aortic openings. The aortic opening is between the two crurae and immediately in juxtaposition to the bodies of the vertebrae. At the right crus pass the greater and lesser splanchnic nerves; while in the left crus course these same nerves, the hemiazygos vein and the thoracic duct. The sympathetic chain passes through a space immediately behind the medial lumbocostal arch and the diaphragm.

### *Thoracic Duct*

The thoracic duct is the means of drainage of lymph and chyle into the blood stream from the entire body with the exception of the right side of the head, neck and thorax and the right upper limb. The latter is conveyed through the right lymphatic duct which empties into the junction of the right subclavian and internal jugular veins forming the right innominate vein. The cisterna chyli is immediately in front of the body of the 2nd lumbar vertebra in a position posterior to the aorta and inferior vena cava. Several lymphatic twigs as well as lumbar lymph nodes may be encountered during a lumbar sympathectomy. The lumbar sympathetic ganglia are in a position posterior to these lumbar lymph nodes. Ordinarily, these lymph nodes and their lymphatic vessels are not disturbed during sympathectomy. At times lymph nodes with intervening lymphatic vessels may be mistaken for the sympathetic chain. Lymphatics are not as tough as the sympathetic chain which withstands much pulling and tugging. The thoracic duct is an upward extension of the cisterna chyli. It extends up into the chest cavity through the aortic opening of the diaphragm. In the chest cavity it ascends through the posterior mediastinal space between the aorta and the azygos system of veins From a midline position up to about the fifth thoracic vertebral body, it extends somewhat toward the left and going up behind the arch of the aorta to the upper end of the thorax at the base of the neck. It is behind the left subclavian artery between the esophagus and the left pleural sac. In the neck, it forms an arch 3 to 4 cm. above the clavicle, and it passes in front of the anterior scalene muscle and the subclavian

artery and its branches. It ends at the junction of the left subclavian vein and the left internal jugular vein. In this position it is immediately posterior to the left common carotid artery, the left internal jugular vein and the vagus nerve.

In doing a thoracolumbar sympathectomy, the thoracic duct may be injured, particularly on the left side. Several twigs on the right side may also be injured. When an injury does take place, chylothorax may occur. If the injury is noted at the time of the operation, limpid, clear fluid is seen to escape from the cut vessel. This should be meticulously ligated. In doing a stellate ganglionectomy, by the anterior approach in the neck, the thoracic duct on the left side may be encountered, but not usually, since the dissection is posterior to this structure. If the subclavian vein and artery both are behind the anterior scalene muscle, then some such difficulties may be encountered and care should be taken not to injure this important lymphatic duct.

### *External, Common Iliac Veins and the Inferior Vena Cava*

The external iliac vein is a continuation of the femoral. It begins behind the inguinal ligament and extends upward at the edge of the lesser pelvis and unites with the hypogastric to form the common iliac vein at the sacroiliac articulation. On the right side it lies at first medial to the artery and as it extends upward it becomes posterior. On the left side it is medial to the artery all the way.

The common iliac veins join to form the inferior vena cava to the right of the fifth lumbar vertebral body. The right common iliac vein is shorter than the left and ascends nearly vertically behind and lateral to the common iliac artery on the right side. The left common iliac vein which is longer than the right is at first medial and then is behind the right common iliac artery. The iliolumbar and lateral sacral veins empty into the common iliac.

The inferior vena cava which is found to the right of the midline and begins at the fifth lumbar vertebral body extends up on the right side of the aorta to the heart after receiving the lumbar, the right spermatic or ovarian, the renal, the suprarenal, the inferior phrenic and the phrenic and the hepatic veins

The lumbar veins are four in number on either side They are formed by the dorsal tributary carrying blood from the back muscles and the vertebral structures and the anterior tributary collecting blood from the abdominal wall and also intercommunicating with the epigastric veins The left lumbar veins are longer than the right and reach the inferior vena cava posterior to the aorta. In front of the transverse processes of the lumbar vertebrae, the lumbar veins intercommunicate to form the ascending lumbar vein. This serves to connect the azygos and the hemiazygos veins of the common iliac and iliolumbar veins. On the right side the lumbar veins are anterior to the sympathetic chain in about 20 per cent of the cases.

### *The Iliohypogastric, the Ilioinguinal and the Genitofemoral Nerves*

The iliohypogastric nerve arises from the first lumbar. It courses down and laterally in front of the quadratus lumborum to the iliac crest and divides into lateral and anterior cutaneous branches

The ilioinguinal nerve which is smaller than the iliohypogastric also arises from the first lumbar. It may be seen extending down paralleling the iliohypogastric on the anterior surface of the quadratus lumborum and iliacus muscles. It pierces the transversus near the anterior border of the iliac crest and passes through the obliquus internus in company with the spermatic cord. It supplies the skin of the upper and medial part of the thigh and the genitalia.

The genitofemoral nerve is given off from the first and second lumbar nerves. It is seen in lumbar sympathectomies as it courses through the psoas major muscle emerging from its medial border at the level of the third lumbar interspace. It descends on the surface of the psoas major and divides into the external spermatic and the lumboinguinal nerves. It is important not to injure the genitofemoral nerve in lumbar sympathectomy as this may give rise to a painful neuritis.

### *Common Iliac and External Iliac Arteries*

The abdominal aorta terminates into the common iliac arteries which are about 5 cm. long. This occurs at the level of the 4th lumbar vertebra and slightly to the left of the midline. The common iliac vessels extend downward and laterally and at the lumbosacral junction, they divide into the external iliac and hypogastric arteries. The external iliac below the inguinal ligament continues as the femoral artery. The hypogastric arteries supply the pelvic organs. The common iliac artery on the right side is a little longer than on the left and it crosses obliquely to the right. Just before it divides into its two terminal branches, the ureter is in a position anterior to the common iliac artery. Posterior to the artery are the common iliac vein and the inferior vena cava. The latter is also lateral and to the right of the artery. The left common iliac vein is on its medial aspect as it comes up to join with the right common iliac to form the inferior vena cava.

On the left side, the common iliac artery is in relation with the ureter anteriorly and posteriorly it is on the bodies of the 4th and 5th lumbar vertebrae. The common iliac vein is in a position medial and behind the artery, and laterally, the artery is in juxtaposition to the psoas muscle.

The hypogastric artery is about 4 cm in length and it extends into the pelvis from the level of the lumbosacral junction to the sciatic foramen. Through its anterior and the posterior trunks, it supplies the various organs in the pelvis.

The external iliac artery extends from the lumbosacral junction onward and laterally on the inner border of the psoas muscle to the thigh, midway between the anterior superior iliac spine and the symphysis pubis, and under cover of the inguinal ligament. The external iliac vein is on its medial side Laterally, and posteriorly, it is in relation with the psoas major muscle. Its two important branches are the inferior epigastric and the deep iliac circumflex vessels. The former is given off just above the inguinal ligament. It extends forward in the subperitoneal tissue and then upward on the medial aspect of the abdominal inguinal ring. It pierces the fascia of the transversalis muscle and it passes between the posterior layer of the rectus sheath and the rectus muscle. It gives off

*(Continued on page 354.)*

An incision about 5 to 6 inches long is made from the tip of the 11th rib to a point just above the umbilicus. The skin edges are undermined superiorly, inferiorly and laterally. The various abdominal muscles are now incised, the fibers being separated in a direction as shown in *1*. The extent of the incision may be seen at *a*. The external oblique and conjoined tendon is incised in direction *b*. The incision of the internal oblique along the length of the muscle fibers is at *c*, and *d* that of the transversalis.

The anatomy of the anterior abdominal wall is given in *2;* the muscle fibers and their direction are shown. At *a* the external oblique; *b* internal oblique; *c* rectus abdominis; and *d* transversalis may be seen.

It is important to coagulate or ligate any bleeding points that are encountered for complete hemostasis.

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### *External Oblique Muscle*

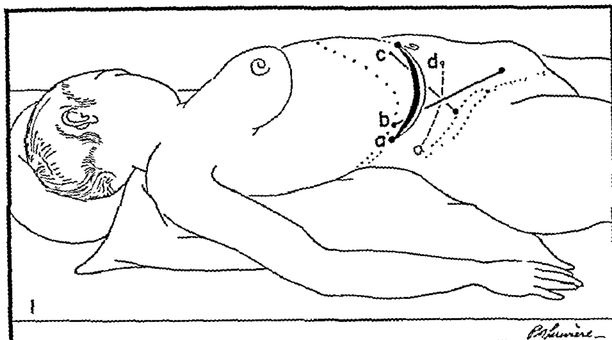
The external oblique muscle arises from muscular digitations from the lower borders of the lower eight ribs, digitating with some of the bundles of the serratus anterior muscle and the latissimus dorsi. The most posterior fibers and those arising from the lowermost ribs extend down and insert in the anterior portion of the iliac crest; whereas, the middle and upper fibers end in the aponeurosis of the external oblique muscle, which, with its fellow on the opposite side, covers the anterior aspect of the abdomen. The linea alba is the portion of the aponeurosis of the two sides meeting at the midline and extending from the xiphoid to the symphysis. The portion of the external oblique aponeurosis which is attached to the anterior superior iliac spine and the pubic tubercle constitutes the inguinal ligament.

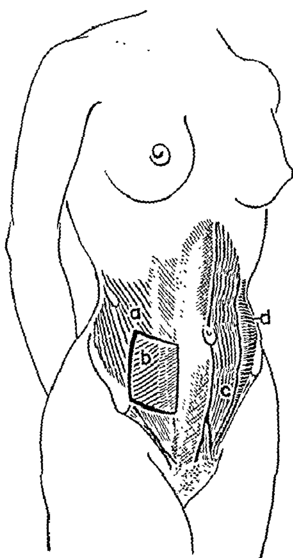
### *Internal Oblique Muscle*

The internal oblique muscle arises from the inguinal ligament, the iliac crest and the lumbodorsal fascia. The fibers extend medially and upward, except those fibers which arise from the inguinal ligament region, which extend medially in a horizontal line. The fibers insert into the costal cartilages of the last four ribs, and into the aponeurosis of the internal oblique which divides into two layers. The superficial layer joins with the aponeurosis of the external oblique to form the outer layer of the rectus sheath. The deeper layer joins with the aponeurosis of the transversalis and forms the deeper layer of the rectus sheath. More inferiorly, it forms the inguinal aponeurotic falx and is also attached to the crest of the pubis behind the lacunar ligament.

### *The Transversus Abdominis Muscles*

The transversus abdominis arises from the lumbodorsal fascia, the iliac crest and from the lower six ribs, interdigitating with the diaphragm. Inferiorly, this muscle is inserted along with the internal oblique to the inguinal aponeurotic falx and to the linea alba, while its superior half blends with the posterior layer of the aponeurosis of the obliquus internus, to form the posterior layer of the rectus sheath.




1. *Position of patient and incision.*
   a. Skin incision from 11th rib to above *umbilicus.*

Direction of fibers of
   b. External oblique.
   c. Internal oblique.
   d. Transversalis.

2. Muscles of anterior abdominal wall.
   a. External oblique.
   b *Internal* oblique.
   c. Rectus.
   d. Transversalis.

In *3* the skin incision has already been made and the skin is being undermined to expose the external oblique and the conjoined tendon. Medially the aponeurosis of the external oblique and the sheath of the rectus abdominis can be seen. The direction of the incision through the external oblique can be seen at *b*. The muscle fibers are separated with scissors.

In *4* the direction of the incision through the internal oblique is seen. This also shows the extension of the incision into the sheath of the rectus. In some instances, one may have to extend the incision to involve the rectus sheath, and if necessary, also to include the rectus muscle. This is very seldom necessary.

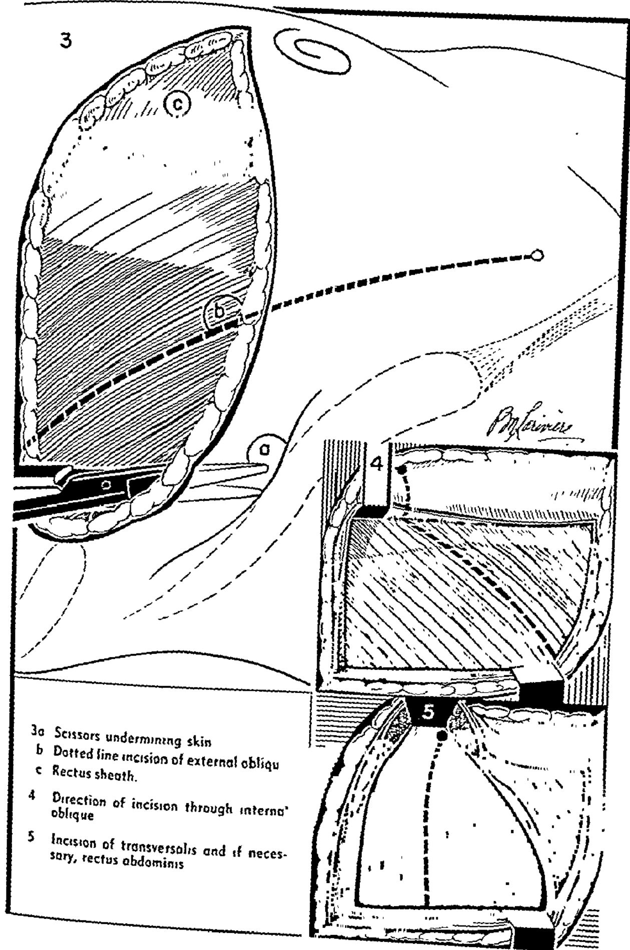
In *5* the incision through the transversalis, the rectus sheath and the rectus muscle is shown. The separation of the transversalis laterally and posteriorly is extended in order to reach the posterior abdominal wall. By this method the reflection of the peritoneal lining from the posterior abdominal wall is facilitated. It is important in this procedure to insure complete hemostasis and to ligate or cauterize all bleeding points.

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*The Linea Alba, the Rectus Sheath, and the Rectus Muscle*

The linea alba is the median fibrous intercommunication between the aponeurosis of the external oblique on the one side and on the other. The rectus sheath is a layer of fascia covering the entire length of the rectus muscle anteriorly; and only a portion of its posterior aspect down to the so called linea semicircularis. From this level down, the rectus muscle is covered posteriorly by the transversalis fascia and the peritoneum. The rectus sheath is made up of the aponeurosis of the internal oblique and the external oblique anterior to the rectus muscle, and the aponeurosis of the internal oblique and the transversalis posterior to the muscle.

The rectus abdominis is a flat, long and narrow muscle which extends from the 5th, 6th and 7th ribs and costal cartilages to the symphysis pubis It arises from the symphysis by two tendons, one, from the lateral portion of the crest of the pubis and the other from the fibrous covering of the symphysis The latter interlaces with its fellow on the opposite side The rectus muscle is characterized by the presence of so-called tendinous inscriptions which are fibrous bands, usually three in number. One is usually at the umbilicus, the other at the tip of the xiphoid, and another in between these two points These tendinous inscriptions do not completely invade the muscle and anteriorly they are adherent to the posterior aspect of the anterior rectus sheath.




3a Scissors undermining skin
b Dotted line incision of external obliqu
c Rectus sheath.

4 Direction of incision through interna' oblique

5 Incision of transversalis and if necessary, rectus abdominis

After having made the incision through the three layers of muscles along the line of their fibers, good exposure is obtained by making these openings sufficiently large. The peritoneal lining is now carefully separated from the lateral and posterior abdominal wall under direct vision, *6*. As the left hand retracts the peritoneal lining away one may see the field; particularly one may identify any bleeding points. As the dissection proceeds it is important to realize that the iliacus and quadratus lumborum muscles are about 2 inches posterior to the psoas group. The dissection should not be extended between the psoas and quadratus lumborum and the iliacus muscles, but the psoas should be exposed. As the psoas is palpated, simulating a rope-like structure, crossing the incision from above downward, the parietal peritoneal lining is separated from this muscle. The gutter between it and the vertebral column is dissected with care.

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*The Lumbar and Pelvic Sympathetic Chain*

The lumbar sympathetic ganglia are usually four in number and they are interconnected to form the ganglionated chain in the lumbar region. They are in a position in front of the vertebral column and at the junction of the medial margin of the psoas major and the vertebral column. The lumbar ganglionated chain extends to the thorax through the medial lumbocostal arch. Inferiorly, it becomes continuous with the pelvic portion of the chain in a position behind the common iliac artery. The white rami communicantes reach the lumbar ganglia from the first, and second and also possibly the third lumbar spinal nerves. Gray rami communicantes are given to all of the lumbar nerves. Most of the white rami communicantes for the lower extremities pass through the ganglia and synapse with postganglionic cell bodies in the walls of structures supplied. Insofar as the lower extremities are concerned a lumbar ganglionectomy in fact amounts to a preganglionic type of sympathectomy as concerns blood vascular innervation The pelvic portion of the sympathetic system consists of four or five small sacral ganglia which form a continuation of the ganglionated chain and converge to end in front of the coccyx in a small ganglion called the *ganglion impar* No white rami communicantes enter these ganglia, their preganglionic fibers have their origin in the lower thoracic and lumbar white rami.

[illegible]
posterior abdominal wall.

7a. Quadratus lumborum
b. The edge of psoas.

Dissection of the structures at the junction of the psoas with the vertebral bodies may be difficult. There may be large amounts of fatty areolar tissue and in other instances, for a good exposure, the psoas may be depressed with a flat retractor. It is important to palpate the bodies of vertebrae from time to time for orientation. In particular it is important to know that one is definitely above the sacral promontory against the bodies of the 4th, 3rd and 2nd lumbar vertebrae. On the right side the inferior vena cava and lumbar veins are encountered and the sympathetic chain is found in a position posterior to the inferior vena cava. The sympathetic chain in the majority of cases may be felt with the finger as a ganglionated chain of tough material. In other instances the chain may be very small and may not be palpated with the finger. In a certain number, the lumbar veins cross over the sympathetic chain; in others, the lumbar veins are posterior to the sympathetic chain. For a good exposure of the sympathetic chain one has to retract the vena cava. If a lumbar vein crosses the sympathetic chain anteriorly, then the vein may be doubly clipped and cut, or the sympathetic chain may be sectioned below the level of the vein and pulled from under it as the dissection is continued upward. Ordinarily, the 4th lumbar is the first ganglion exposed and the dissection may be continued upward from this level to the 3rd and the 2nd. At times the 2nd and 3rd may be a single ganglion elongated and tubular in shape. Various twigs running off from the ganglion are cut.

In *8* and *9* at *a* the inferior vena cava is retracted. At *b* the lumbar vein is doubly clipped and cut. The psoas major is shown at *c; d* is quadratus lumborum and *e* the iliacus. In *10* the sympathetic chain has been separated from its bed and the 4th and 3rd lumbar ganglia are excised.

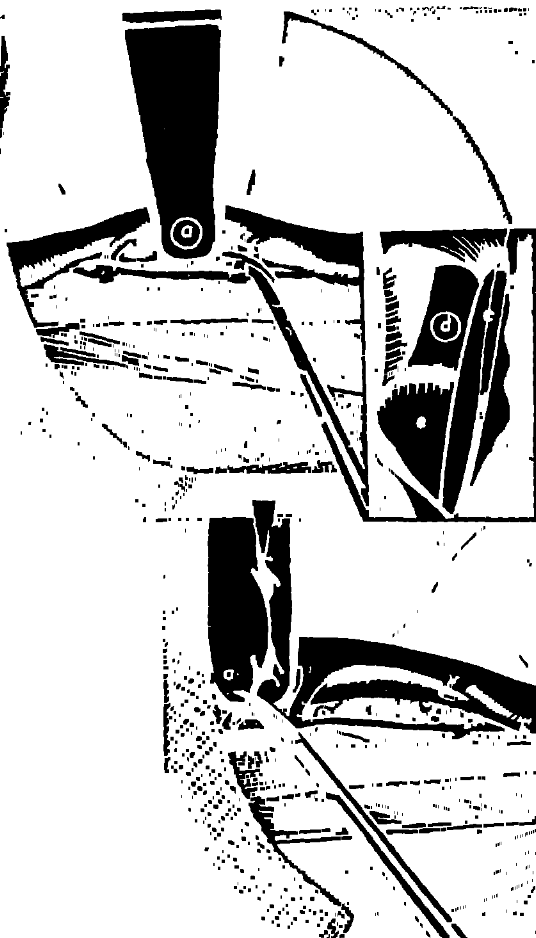
After excision of the ganglionated chain, and the removal of retractors, gauze and towels, one inspects carefully the posterior abdominal wall for bleeding points as the peritoneal lining and its contents are permitted to fall posteriorly.

With good retraction the extent of the incision should be seen, both laterally and medially, superiorly and inferiorly in order to suture various muscles and enable good closure. These muscles are all approximated with interrupted chromic sutures The skin is closed with subcuticular and interrupted silk sutures.

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*Common Iliac and External Iliac Arteries (Concluded)*

many twigs It also communicates with the superior epigastric artery, a terminal branch of the internal mammary. The deep iliac circumflex artery is given off from the lateral aspect of the external iliac just above the inguinal ligament It courses between the transversalis muscle and the internal oblique, and communicates with the iliolumbar and the superior gluteal arteries.



*In 11* the findings on the left side are shown. The skin incision, the separation of the muscles, the section of the muscles along their fibers are exactly the same as on the right side. The peritoneal lining and the contents of the abdomen are carefully separated from the lateral and posterior abdominal wall until the psoas muscle is identified and the junction of the psoas with the vertebral bodies is dissected free. In *11* the sympathetic chain and aorta are shown. The aorta is more medially placed than the sympathetic chain and it is somewhat easier to see and feel the chain on the left side. The chain is being cut at *a*, and the 4th, 3rd and 2nd ganglia have been exposed. After *excision of the ganglionated chain, the peritoneal lining with its contents is* permitted to drop posteriorly and the various muscles are approximated with interrupted chromic and the skin is closed in two layers with silk.

In *12* the anatomy of the posterior body wall anterior to the vertebral bodies is shown. The aorta at *b* and the vena cava at *a* may be seen. It should be noted that the sympathetic chain on the right side is under the vena cava The sympathetic chain on the left side is lateral to the aorta.

In *13* the vena cava and the tributaries to the same are shown. The vena cava is seen at *a*; *b* is a lumbar vein; *c* is the ascending lumbar vein which is somewhat farther away on the left than on the right and becomes continuous with the azygos system of veins in the thorax. The lymphatic chain, which may appear very similar to the ganglionated sympathetic chain, is shown at *d*. The middle sacral vein is at *e*.

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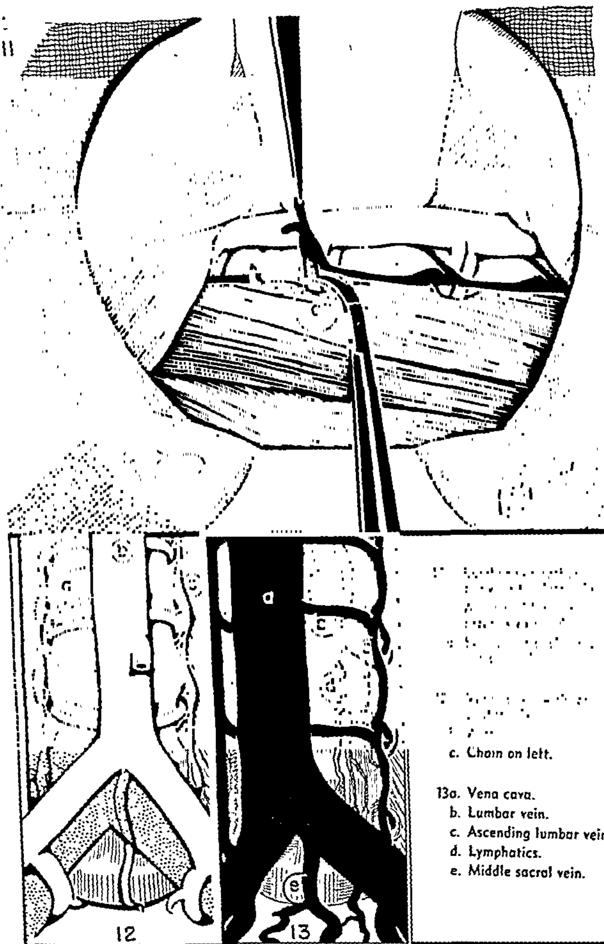
### *Quadratus Lumborum, Psoas and Iliacus Muscles*

The quadratus lumborum is a quadrangular muscle. It extends from the iliac crest and the iliolumbar ligament to the lower border of the last rib, also being attached to the transverse processes of the upper four lumbar vertebrae.

The psoas muscle is attached superiorly to the transverse processes of the lumbar vertebrae and the sides of the bodies. Inferiorly, it is attached to the lesser trochanter of the femur. The psoas minor, which may be absent, arises superiorly from the 12th thoracic and 1st lumbar vertebrae and inferiorly, it is attached to the iliopectineal line.

The iliacus covers the anterior and medial surface of the iliac bone being attached superiorly to the iliac crest, to the iliolumbar and sacro-iliac ligaments and the sacrum. Inferiorly, it is attached to the femur just a little below the lesser trochanter.

In doing a lumbar sympathectomy, the iliacus muscle, the quadratus lumborum and the psoas muscles are encountered. The psoas is at least an inch to an inch and a half anterior to the iliacus muscle and consequently near the anterior abdominal wall.




[illegible]

[illegible]

c. Chain on left.

13a. Vena cava.
b. Lumbar vein.
c. Ascending lumbar vein.
d. Lymphatics.
e. Middle sacral vein.

Through a median incision from the umbilicus to the pubis, slightly the right of the midline, the rectus sheath is incised and the rectus musc is dissected laterally. The peritoneal lining is identified, tented, and car *fully incised inferiorly so as not to injure the bladder wall.* The various i testinal loops are carefully retracted and the promontory of the sacrum identified. With good retraction the region between the two common ili vessels on either side and the 5th lumbar vertebral body posteriorly ma be well visualized. The posterior peritoneal lining is now incised. The pr sacral nerves are isolated and excised. The peritoneal lining over the pr montory is closed and the remaining incision of the anterior abdominal wa is closed in layers.

In *1* the position of the incision is shown. In *2* the presacral nerve at the ganglionated chain at *b*, and the sacral nerves at *c* are shown. In *3* th incision has been made through the rectus sheath and the rectus muscle i retracted laterally to expose the peritoneal lining. In *4* the peritoneal linin has been tented and nicked preparatory to incision with scissors.

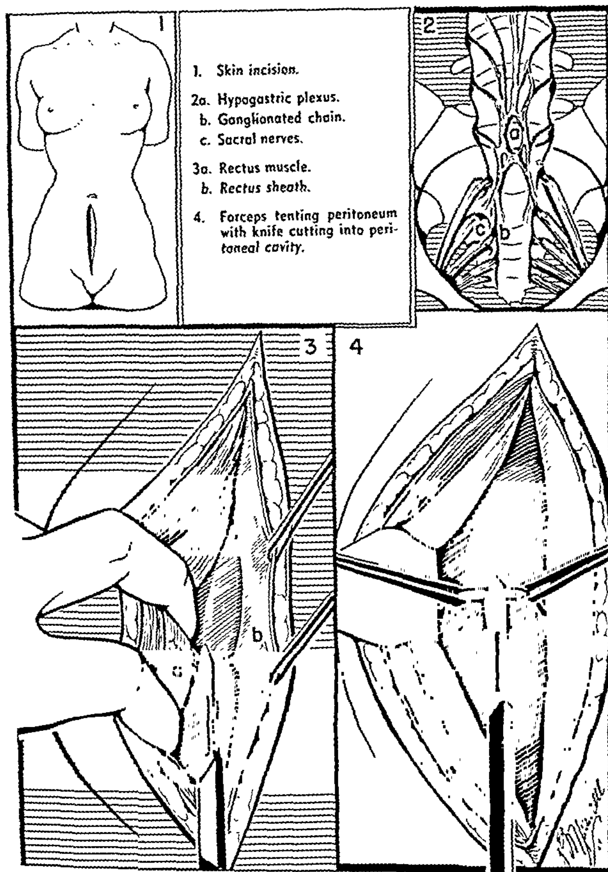
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### *Hypogastric Plexus*

The hypogastric plexus is made up of fibers which come from the aortic plexus as well as from the lumbar ganglia and is situated in front of the fifth lumbar body and the promontory of the sacrum. The hypogastric plexus contains visceral efferent and afferent fibers of thoracolumbar origin. *It is found between the two common iliac arteries and inferiorly* it extends downward to form two masses of nerve bundles called the pelvic plexuses The latter contain fibers not only from the thoracolumbar outflow but also from the *second, third, and fourth sacral* nerves (parasympathetic). The pelvic plexuses supply the various viscera in the pelvis.

### *The Abdominal Aorta*

The abdominal aorta extends down from the aortic opening of the diaphragm in front of the vertebral column and ends at the body of the fourth lumbar vertebra dividing into the two common iliac arteries Its course is slightly to the left of the midline throughout. It gives off many visceral branches including the celiac, the superior mesenteric, the inferior mesenteric, the suprarenal and the inferior spermatic or ovarian arteries. The parietal branches include the inferior phrenic, the four lumbars and the middle sacral arteries.


1
1. Skin incision.
2a. Hypogastric plexus.
b. Ganglionated chain.
c. Sacral nerves.
3a. Rectus muscle.
b. Rectus sheath.
4. Forceps tenting peritoneum with knife cutting into peritoneal cavity.
2
a
c
b
3
4
b

In 5 the promontory of the sacrum has been exposed after carefully retracting the intestines. At *a* the common iliac vessels may be seen. The peritoneal lining of the promontory is being nicked. At *b* one sees the *sigmoid*; at *c* the uterine dome; at *d* the ovary; and *e* the upper end of the bladder.

In 6 the peritoneal lining over the promontory has been incised. The presacral nerve with *various twigs extending from* the sympathetic chain has been isolated. At *a* the presacral tissue is being ligated preliminary to section. At *b* one of the twigs off the sympathetic chain is being cut. The peritoneal lining and the iliac vessels are seen at *c*.

In 7 the peritoneal lining of the promontory has been closed. The opening of the anterior abdominal wall is closed with continuous plain catgut for the peritoneum, and interrupted silk sutures thereafter.

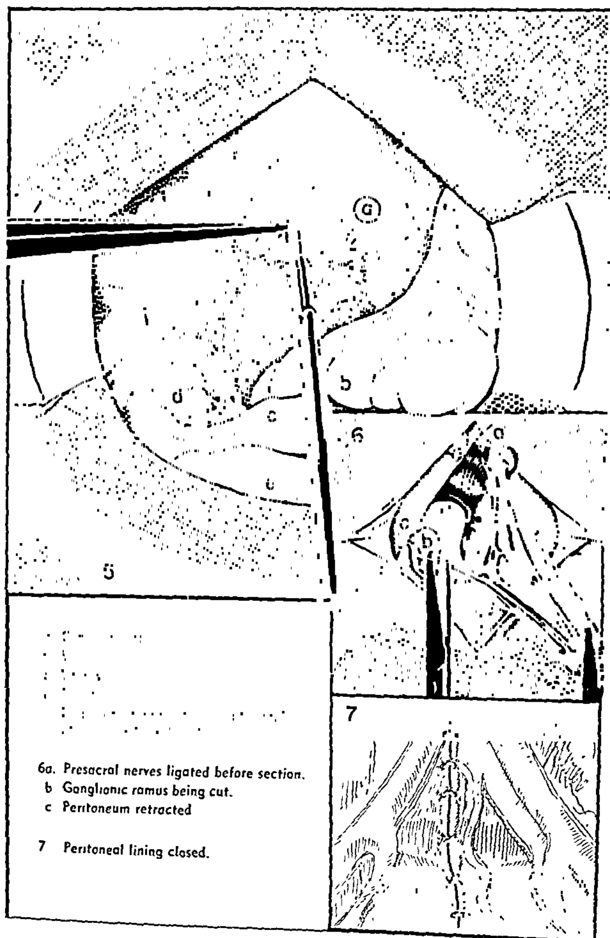
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## *Blood Supply of Anterior Abdominal Wall*

The blood supply of the anterior abdominal wall is through the last four intercostal vessels and the 1st lumbar laterally, through the superior epigastric branch of the internal mammary and the inferior epigastric branch of the external iliac, medially. These lateral and medial blood vessels intercommunicate, with resultant extensive network between the various muscular layers

The intercostal vessels pierce the anterior termination of the corresponding lower four interspaces and enter the deep surface of the external oblique muscle. The 9th and 10th are much smaller than the 11th and 12th intercostal vessels. They divide into a deep and superficial branch. The deep branch supplies the internal oblique and transversalis, whereas a superficial branch is between the external oblique and internal oblique supplying these muscles. Corresponding nerves extending anteriorly in the abdominal parieties are in a position just below the corresponding arteries, while the corresponding veins are just above the arteries. A branch of the 1st lumbar artery is given off in the immediate vicinity of the anterior superior iliac spine. This artery may be cut in some cases for better exposure in appendectomy where the internal and external oblique are sectioned. The superior epigastric artery is a continuation of the internal mammary and it enters the posterior aspect of the rectus muscle, and courses down anterior to the posterior rectus sheath. It pierces the muscle, supplies the same and it also communicates with the inferior epigastric artery, which is a branch of the external iliac. It enters the posterior aspect of the rectus muscle and extends up between it and the transversalis fascia to the linea semicircularis, thence it extends up between the muscle and the posterior layer of the rectus sheath to supply the muscle as well as to intercommunicate with the superior epigastric artery.

In doing a lumbar sympathectomy, the superficial branches of the intercostal vessels between the internal and the *external oblique muscles* are encountered. They may be sectioned necessitating ligature or cautery. The deep branches which are smaller may be involved in exposing the transversalis muscle and between it and the *internal oblique muscle*




6a. Presacral nerves ligated before section.
b Ganglionic ramus being cut.
c Peritoneum retracted

7 Peritoneal lining closed.

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# PERIPHERAL NERVOUS SYSTEM

# Historical Considerations

IN THE Hippocratic period there is no indication that peripheral nerves were distinguished as an anatomical entity from other structures such as the tendons in the extremities. Later, Galen is reported through his extensive anatomic and physiologic knowledge to have recognized that paralysis of a part followed division of its particular nerve, holding the belief that damage to nerves represented an irreparable injury. This latter concept persisted for many centuries.

During the medieval period of surgery, there are meager records which indicate that injured nerves were treated by nerve suture. Well-documented military surgery of the 16th century indicated that both Wiseman in England and Paré in France recognized the occurrence of nerve injuries but neither indicated the possibilities of restoration of function by nerve suture.

An important general concept up to and into the 19th century was that spontaneous regeneration of nerves occurred. This belief probably encouraged conservatism in dealing with nerve injuries. Swan, Wood, Velpeau, and Virchow supported this doctrine.

In the meantime, important experimental concepts proving regeneration were being developed by Cruikshank in 1776, Fontana in 1787, and Haighton in 1795. There were contrary experimental results, notably those of Arnemann in 1787, who has been reported as the first man of modern times known "with certainty to have sutured a divided nerve". Arnemann found no return of function after nerve suture and noted that the distal portion of the nerve became shrunken and changed its appearance even after suture. Thus, by not allowing sufficient time to elapse, he wrongly concluded that regeneration was not possible.

Clinical surgeons in the 19th century showed no favor to the experimental concepts which had proved that regeneration occurs. Delpech in 1815, Richerand in 1812, and G. J. Guthrie in England dismissed the use of nerve suture. The latter in *Treatise on Gunshot Wounds and Injuries* in 1827, reported that he knew of no case in man of recovery of function after division of a main nerve. It is of interest, however, in this same period that Larrey held the view that recovery following nerve interruption was possible. Further important experimental work was done by Prevost in 1826 who demonstrated regeneration as well as the important fact that such a process was slow In 1828, Flourens added weight to the theory of regeneration.

His nerve suture technique consisted of approximating the nerve ends by suturing the tissue about the nerve.

It is reported that the first modern nerve suture was done in 1836 by Baudens who did a primary suture of a brachial plexus wound caused by a saber cut. The method of suture was similar to that used by Flourens experimentally. There was still, however, little attention given to the treatment of nerve injuries by this method. During the American Civil War, in spite of the interest of Mitchell in nerve injuries and the fact that he recommended treatment by means of nerve suture, there is no evidence that patients with nerve wounds were treated by means of surgical repair. It is of interest that Mitchell held the belief that peripheral regeneration occurred with normal nerve fibers developing in the distal stump of a divided nerve irrespective of a union of the proximal and distal portion. Thus he did not accept the theory of Waller which had indicated that regeneration was a downward growth of new axons from the proximal segment joined to the distal portion. Finally, the work of Ranvier, Kolliker, His and later Howell and Huber settled the mechanism of regeneration.

Various techniques of nerve suture gradually evolved from "through and through" suture with heavy suture material to paraneural suturing as done by Flourens. Mikulicz in 1882 used what has now been termed the sling suture, or a suture placed through the proximal and distal ends of the nerve for apposition. During World War I it became a custom to resect the neuromatous portions of the interrupted segments by means of a sharp blade before an approximation was made. In this period also employment was made of internal and external neurolysis. Injection of saline as a means of internal neurolysis was used by Murphy as early as 1907. The importance of maintaining funicular alignment was discussed at this period and generally accepted. Stretching to overcome gaps became popular with little attention being given to the hazard of such management. Approximation of nerve segments without suture material was employed by Ballance and Duel in 1932, in a nerve graft for the facial nerve in the facial canal Later, a modification of this method was used by Young and Medawar and more recently by Tarlov. Of the many types of suture material used for nerve approximation, the most recent and favorable is a fine tantalum wire which has the advantage of being radiopaque. Thus a disrupted suture line may be identified by means of roentgen studies. Since the beginning of the 20th century, an interest in bridging nerve gaps has attracted the clinical surgeon. Many types of tube methods have been suggested and tried, with few satisfactory results. The most promising method would appear to be the use of a nerve graft as reported recently by Seddon.

# Anatomy, Physiology and Pathology

THE PERIPHERAL nervous system consists of afferent and efferent fibers comprising nerve roots, plexuses and peripheral nerves. It constitutes an intricate system of communication connecting the central nervous system with afferent sources of stimulation and effector organs.

The peripheral nerve is a yellowish white, cord-like structure. In many instances an artery is present on its surface coursing in the direction of the nerve. Peripheral nerves consist of nerve fibers which are held together with connective tissue. The connective tissue lining of peripheral nerves is of some surgical significance. The portion which holds individual nerve fibers together into bundles is called endoneurium; the portion which holds several nerve bundles together into larger bundles is called perineurium, whereas larger bundles forming the nerve proper are covered by the epineurium.

When a peripheral nerve is injured there may be an anatomical or physiological interruption of function. In the presence of an anatomical interruption or an irreversible physiological interruption, the portion distal to the point of injury undergoes degeneration, while the proximal end of the nerve regenerates In the distal end, the axons covered with myelin rapidly disintegrate within the Schwann tubules. The empty Schwann tubules remain but gradually become reduced in size due to connective tissue proliferation. In about three months the distal tubule becomes a hollow structure. Later, the Schwann tubule loses its ability to aid in regeneration. Consequently, time becomes an important factor in obtaining good results following nerve suture.

While the distal portion of the nerve degenerates, the proximal end of an injured nerve regenerates with growth of the axons and proliferation of the cells of Schwann. Under ideal circumstances, the axons extend into the hollow tubules in the distal portion. Growth, under these circumstances, is estimated at 1 5 to 1.7 mm. per day. If the cut nerve ends are not in proper approximation, the regeneration of the proximal end proceeds abnormally. The regenerating fibers twist and turn and collectively result in the formation of a neuroma. A bulbous enlargement at the proximal end and a smaller but similar enlargement occurs at the distal end in lacerated and nonsutured nerves.

Immediately following the interruption of an injured nerve, muscles in-

nervated by it are paralyzed, losing their tone and becoming flaccid. At the end of about a week, the response to faradic current is lost. Still later, wormlike movements appear upon stimulation with galvanic current (reaction of degeneration). The skin surface supplied by the affected nerve is anesthetic from the time of injury. The area of anesthesia is also dry, due to sudomotor paralysis in the area of the sensory loss. Later, other trophic changes, such as smoothness, shininess, exfoliation, and atrophy may result in serious functional disturbance of the affected part. The greater the atrophy, the poorer the results of surgical treatment in late cases. The highly specialized small muscles of the hand have little or no return of function after the "near atrophy" point has been reached.

The cross-sectional anatomy of the nerve presents functional distribution typical for that nerve. Consequently, in nerve suture, it is important that the anterior and medial border of the sectioned nerve be sutured to the anterior and medial border of the distal segment. Rotation of the proximal end to the distal end will result in growth of fibers so that a motor bundle may grow into a sensory bundle of fibers with resultant poor functional restoration. Of course, this is true in mixed nerves. In purely sensory and motor nerves improper approximation due to rotation may not be as serious.

Peripheral nerves may be injured by lacerations, by low velocity injuries and by high velocity wounding. There may be chronic pressure on a nerve by scar with resultant dysfunction. There may be a physiological interruption of nerve which appears to be anatomically intact. Such a physiological interruption may result in closed injuries due to contusion of nerves and in open injuries due to high velocity wounding by a shell fragment or bullet. The commonest type of physiological interruption of nerve function is with reversible axonal damage with recovery of the nerve function in a matter of days or weeks (neurapraxia). The more severe grade of damage may produce axonal degeneration with intact tubules. Again, recovery occurs more gradually and may take several months (axonotmesis). A third type of physiological interruption of nerve function is associated with degeneration of the axons as well as the sheath of Schwann through the area of damage. Under these circumstances, fibrous tissue replaces the neural substance with eventual complete anatomical block occurring (neurotmesis) Regeneration may occur only after the scarred portion of the nerve is resected and is followed by end-to-end anastomosis.

*The first step in the proper management of a nerve injury* is the recognition of the existence of nerve dysfunction. The location of the injury should arouse suspicion as to the presence of nerve involvement. Confirmation of such an injury may be made by simple tests for impairment of sensory and motor function. A short synopsis of the more important diagnostic features of nerve involvement is given on page 374. It is also important to note the presence of associated injury to other structures, particularly tendons and muscles. There is concomitant suture of tendons and muscles at the time the nerve suture is effected, in the great majority of cases.

Most civilian nerve injuries are produced by lacerations or penetrating in-

struments of low velocity, or in association with fractures and dislocations of long bones. The lacerated nerves are ideally treated by immediate end-to-end anastomosis. Primary suture in clean cases within twelve hours is the proper method of management.

Early exploration in cases of nerve lesions associated with fracture of long bones is justifiable after complete study of the history, physical findings and roentgenograms. If from an orthopedic standpoint open reduction is the procedure of choice, the involved nerve can also be explored at the same time. Early exploration in ulnar nerve paralysis, associated with fracture of the medial condyle of the humerus is preferable. Anterior transposition of the nerve may then be carried out. Early exploration of primary peroneal paralysis is desirable in injuries of the knee joint, with fracture of the upper end of the fibula. There is a great likelihood of a torn nerve in most cases of primary peroneal paralysis in this type of injury. In fractures of the middle third of the humerus, complicated by radial paralysis, exploration in eight to ten weeks is justified if there are no evidences of returning function. In compound fractures associated with nerve lesions, earlier repair is feasible, particularly with present day antibiotic therapy. A nerve should always be explored if there is no evidence of regeneration three to four months after a fracture of the neighboring bone.

Wounds of nerves produced by high velocity objects such as shell fragments or bullets contrary to civilian injuries are best treated by delayed suture. This period of delay permits the injured proximal and distal segments to demarcate and reveal the extent of damage not visible to early gross inspection. Demarcation usually occurs by the third week according to Haymaker. At this time the tissue reaction of the surrounding structures has also resolved. A high velocity wound involving nerves is best treated by debridement and closure and delayed nerve suture four to six weeks following healing.

In the presence of infection it is best to wait for four to six weeks after complete healing has taken place before nerve suture is attempted. The use of antibiotics may be efficacious in combating potential infection in such cases.

# Principles in Surgical Technique

*1. Preparation.* Before operation, a complete and accurate record of the patient's disability should be obtained. It is necessary to evaluate voluntary muscle reactions, sensory abnormalities, and sudomotor function. Electrical stimulation of the affected parts may also be helpful. Electromyography has been found useful. These records may then be used with records obtained later for comparison.

The preoperative preparation for the extremity includes complete shaving, followed by soap and water wash, and cleansing with ether and alcohol. Thorough cleansing of the hands or feet is indicated. In the upper extremity it is often necessary to expose the hand to observe finger and hand movements. Fingernails should be clipped and scrubbed well.

Positioning on the operating table is important both to the patient's comfort, as well as to the ease of approach to the operative site by the surgeon and assistants. It is usually best to have all individuals seated during the operation.

*2. Draping.* Draping should be made in such a manner that if there is necessity for extending incisions, this can be done with ease. It is usually practical to insert the prepared extremity through a hole in a laparotomy sheet. Towels may then be used to drape the planned incision. The prepared hand may be covered in such a manner that it can be easily and readily exposed for finger and hand actions.

Hemostasis is no problem in the greatest majority of these cases. A tourniquet should not be used to control hemorrhage during the operation.

*3. Anesthesia.* Many cases of nerve injuries may be repaired under local anesthesia Preoperative sedation, usually using morphine grains $\frac{1}{4}$ to $\frac{1}{8}$, and scopolamine grains $\frac{1}{150}$ to $\frac{1}{300}$ in repeated doses, two hours and a half hour before operation, makes local anesthesia tolerable. The advantages of local anesthesia include voluntary muscle testing which may be of considerable value following suture of tendons. Electrical stimulation is also more effectively used. In some patients, intravenous pentothal anesthesia combined with local infiltration of procaine is used. Spinal anesthesia may be used to advantage in procedures involving the lower extremities when the operation is not prolonged

In complicated cases, it is best to use general anesthesia

*4. Facilities.* Equipment is important in the treatment of peripheral nerve injuries Good lighting and instruments should be available. Fine forceps, fine hemostats, scissors and sharp knives, fine silk or tantalum wire are im-

portant. An electrical stimulator should be available. Particularly in old cases it may distinguish between intact nerve fascicles and completely interrupted fibers.

5. *Incisions.* Incisions are placed to permit ready exposure of muscle and fascial planes. Nerves in general course between muscles. Occasionally, it may be necessary to invade a muscle belly and this should be done by splitting the fibers. When it becomes necessary to sever a muscle, which is rarely the case, the incision is best made at the fascial attachment.

In making an incision one should avoid cuts perpendicular to flexion creases of the skin of the extremities, such as at the axilla, antecubital fossa, wrist and popliteal areas. In some instances, long incisions may be necessary to permit extensive exposure of nerves with maximum mobilization of distal and proximal ends of the involved nerve.

6. *Overcoming Gaps.* The excellence of the results of a nerve suture depends upon the resection of all devitalized tissue of the proximal and distal ends of the nerve before suture. The resultant gap must be overcome without undue tension at the point of the anastomosis. Several means are available.

First, by the use of long incisions, the proximal and distal ends of the nerve may be freed for long distances. The immobilizing influence of major branches may be overcome by neurolysis and separation of these branches off the main trunk for distances of several centimeters.

Second, the extremity may be postured to help bring the nerve ends together. Flexion of the wrist, elbow, knee and thigh are of great use. With ulnar nerve gaps, transplantation of the nerve to the anterior aspect of the elbow with flexion of the elbow may overcome gaps of as much as 10 cms. Following posturing of an extremity, gradual neutralization of the position has to be accomplished postoperatively. So far as possible, nerves should not be under tension. It is best not to depend upon extreme posturing for suture.

Third, nerve transplantation is an important means to overcome gaps. This is particularly true in the case of the ulnar nerve which may be transplanted to the anterior aspect of the elbow joint from the epicondylar groove. The radial nerve in some cases may be removed from the posterior aspect of the humerus to the anterior aspect.

Fourth, bulb suture is a two-step procedure and not to be recommended in the great majority of cases. The proximal and distal segments of the nerve may be joined by a preliminary suture of the neuromatous ends, in conjunction with which joint posturing may be of help. When the extremity has been neutralized, a definitive suture may be accomplished by resection of the neuromatous ends until normal fascicles are encountered. In many cases, microscopic damage to the nerve fascicles with stretch fibrosis causes unsatisfactory results.

Fifth, an experimental method is the use of nerve transplants. Encouraging results have been recently obtained by the use of nerve transplants to overcome gaps in the median, ulnar and other nerves in the upper and lower extremities. Nerve transplants have been used to overcome gaps in the facial nerve with functional restoration. In the majority of nerve wounds in the extremities, it is best to insist upon end-to-end suture if at all possible.

# Diagnosis of Peripheral Nerve Lesions

The diagnosis of a nerve interruption is usually simple. Mistakes are frequently caused by oversight of the possibility of nerve involvement. In many cases a few questions and answers clinch the diagnosis. The location of the laceration should suggest to the examiner the possibility of nerve involvement. The wound in the middle of the palm-wrist junction may be accompanied by section of the median nerve. A more medial laceration may involve the ulnar nerve. An extensive injury of the wrist often involves both the ulnar and the median nerves. A relatively superficial cut over the epicondylar groove on the medial aspect of the arm may involve the ulnar nerve. The radial may be sectioned by a wound of the anterolateral aspect of the arm below its middle third. A injury on the lateral aspect of the head of the fibula may result in injury to the peroneal nerve. The location of the laceration alone should therefore warn of nerve involvement.

The cardinal neurologic features of either anatomical or physiological nerve interruption include sensory changes, motor loss and sudomotor paralysis. In some nerves, the sensory defect is the most prominent, while in others, it is the motor, and in still others, both motor and sensory involvement are quite marked. There is usually sudomotor paralysis in the area of anesthesia in an extremity nerve interruption.

Although a discussion of the anatomy of the various extremity nerves is reviewed in detail later, a few simple diagnostic points follow.

*Facial Nerve.* Section of the facial nerve may occur proximal or distal to the pes anserinus. *When such a section occurs distal to this point the upper* or the lower parts of the face may be involved, or the entire face may be involved In complete involvement, there is paralysis of the forehead muscles, the muscles of expression around the eyes and the mouth, and the platysma in the neck on the affected side. Inability to wrinkle the forehead, close the eye on the affected side and elevate the angle of the mouth are simple physical findings that can be noticed at a glance.

*Median Nerve* Median nerve section may be diagnosed by the presence of sensory loss *in the lateral three and one-half fingers and the corresponding* portion of the palm. These patients also have anesthesia of the distal two phalanges of the index and long, and one-half the ring finger on the dorsal surface. Such a sensory pattern often clinches a diagnosis of median nerve dysfunction There is a motor defect characterized by inability to flex the

distal phalanx of the thumb and index fingers. Opponens pollicis impairment and subsequent atrophy may occur.

*Ulnar Nerve.* Ulnar nerve interruption results in a sensory loss characterized by involvement of the little finger, and one-half the ring finger, the corresponding portion of the palm, and the dorsum of the hand if the section is high enough to be above the dorsal cutaneous branch. There are marked motor phenomena in ulnar nerve involvement with impairment of finger adduction and abduction, thumb adduction, and inability to flex the proximal or distal phalanges of the ring and little fingers. An accurate diagnosis can be based upon sensory loss in the majority of patients.

*Radial Nerve.* The important feature of radial nerve interruption is wrist, finger and thumb drop, with little or no sensory loss. Interruption of the posterior interosseous branch in the forearm impairs only digital extension. The possibility of extensor paralysis from the section of tendons in the forearm should also be entertained.

*Musculocutaneous Nerve.* The diagnosis of injury to this nerve is based upon the presence of paralysis of the biceps muscle. There is loss of sensation on the anterolateral surface of the forearm, with impaired flexion and supination of the forearm and loss of the biceps reflex.

*Axillary Nerve.* A paralysis of the deltoid muscle is diagnostic of axillary nerve dysfunction. This results in weakness of abduction of the arm to the horizontal plane and a sensory defect over the deltoid muscle.

*Brachial Plexus Involvement.* A laceration of the supraclavicular region of the neck with varying degrees of paralysis of the upper limb denotes brachial plexus dysfunction. The upper plexus involvement results in a disturbance in the function of the axillary, musculo-cutaneous and median distribution. The lower brachial plexus involvement is manifested in median, ulnar and radial paralysis.

*Multiple nerve involvement* in the upper extremity: In many instances, more than one nerve is involved, as occurs with the median and ulnar nerves in wrist lacerations. This type of section may be complete, or incomplete, giving varying patterns of sensory loss, some of which are quite confusing.

In the lower extremities, the sciatic and its two terminal branches, the peroneal and tibial are infrequently injured in civilian lacerations. The femoral is even less commonly involved. The leading and gross diagnostic features of interruption of these nerves may be summarized as follows:

*Sciatic Nerve.* Paralysis of flexion and extension of the foot and toes accompanied by a large area of anesthesia involving the foot and leg may be readily observed. The hamstring muscles may be involved in high interruptions

*Tibial Nerve.* There is a paralysis of flexion of the foot and the toes with sensory loss over the sole of the foot. Foot inversion is also impaired.

*Peroneal Nerve.* There is characteristic paralysis of extension and eversion of the foot and toes, with sensory loss along the dorsum of the foot and the lateral aspect of the leg

*Femoral Nerve.* Femoral nerve involvement shows paralysis of the quadriceps femoris with sensory defect along the anterior and medial aspect of the thigh and leg. Extension of the leg is lost, as is the patellar reflex. The thigh cannot be flexed on the abdomen.

*Sacral and Lumbar Plexus* involvement is uncommon in civilian practice. Such injury results in complete or partial paralysis in the distribution of the sciatic and the femoral nerves.

*Tendinous Injuries.* Associated injury to tendinous and muscular structures should be considered and the extent of non-neural involvement carefully ascertained prior to nerve exploration. Preoperative evaluation of the extent of both nerve and tendon involvement is important. The wound should never be entered before such a clinical assessment of the extent of damage has been made and recorded. Tendons after section may retract from view and they may be difficult to secure unless searched for. Not uncommon are examples of the distal ends of nerves sutured to the proximal ends of wrong nerves or to tendons in patients with multiple nerve-tendon injuries.

# Rehabilitation

Like many other surgical procedures, operations upon peripheral nerves require planned, long-term aftercare. The final result is closely dependent upon this phase of rehabilitation. (1) This begins with the injury. The successful outcome partly depends upon the ability of the surgeon to interest the patient in his problem. (2) The nature and extent of the injury and the value of exercise should be discussed with him. He should be told that his paralyzed part deserves all the attention that he can possibly allot to it and that a critical period of ten to twenty-four months exists during which the final outcome is influenced by the exercise of the affected part. Self help should be emphasized as a very important matter to him. After operation, exercise can often be resumed. Although an extremity may be temporarily immobilized by a molded splint about the elbow, the hand may be kept in motion.

After two weeks of immobilization for healing, neutralization is begun. The flexed wrist, elbow, thigh, knee, etc., is gradually extended through a period of another three weeks by weekly reapplication of molded splints. During this five-week period of immobilization galvanic stimulation may be employed on the involved muscle daily. After five weeks massage and limited exercise are gradually expanded.

The use of splinting for paralyzed muscles is intended to prevent damage of the muscle fibers by tension, pull or stretch. Although this is true, it is also true that splinting may be injurious. Fixed joints due to fibrosis of disuse cannot be moved by the healthiest of muscles. In our experience, splinting should be minimized. The patient should understand that when splinting is employed, it is used as a supportive measure for the intervals between exercise and during sleep. The maintenance of dropped fingers, wrist, foot or extremity in a neutral position during such periods is of value. The exact purpose of this immobilization should be explained to the patient. He should be urged to keep the affected part supple and unrestricted. With the help of the physiotherapist, the patient may be taught various types of exercise which will lessen disability, but it must be kept in mind that adequate exercise can only be achieved through the patient's own efforts.

# Neurosurgical Procedures

## Surgical management of nerve lesions

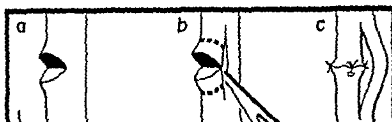
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The peripheral nerves may be injured in lacerating and penetrating wounds, and in association with fracture and dislocation of bones and joints. A peripheral nerve may also be involved by a neoplasm. Tumor tissue may grow within its substance, or invade the nerve structure from without. Examples of various types of lesions are considered in the accompanying figure.

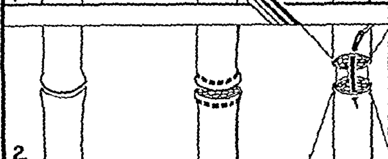
Pertinent anatomical features common to all peripheral nerves should be mentioned at this point. A peripheral nerve is surrounded by connective tissue which is called the epineurium. The epineurium holds together several nerve bundles, each of which is supported by the perineurium. The perineurium surrounds a collection of individual nerve fibers which are in turn held together by the endoneurium. In surgical practice it is simple to incise the epineurium and separate the bundles from one another (neurolysis). Under special circumstances, individual nerve bundles may again be longitudinally incised by splitting the perineurium, but it is quite likely that many individual nerve fibers thus may be damaged.

*1.* In case of a partial section in a fresh wound, the sectioned portion of the nerve should be separated from the intact portion. This is accomplished by means of a sharp-pointed knife, cutting through the epineural and perineural connective tissue. It is important to avoid damage to the intact portion of the nerve. After the separation has been sufficiently accomplished for easy handling of the cut portion, the ends of the latter are now freshened with a razor blade and approximated with interrupted silk sutures, usually four in number, one on either side, one posteriorly and one anteriorly.

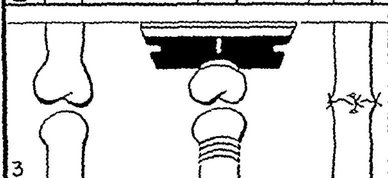
*2* The management of a complete section in a fresh wound is considered. Again, the nerve ends are carefully dissected free from the surrounding tissues.The nerve is freed both proximally and distally to effect a suture without tension. The nerve ends are carefully freshened with a razor blade and sutured with interrupted silk sutures, usually four in number. It is important to avoid rotation of the nerve which disturbs regeneration of fibers. Cross-sectional topography of a sectioned nerve should be preserved and the lateral portion of the nerve above should be sutured to the lateral portion of the lower end, the medial portion to the medial portion; and the anterior and posterior relationship maintained



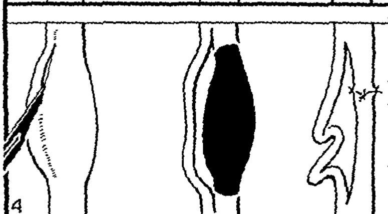

1a. *Partial section.*
b. *Separating the cut portion from the uncut portion.*
c. *Suturing the cut portion.*



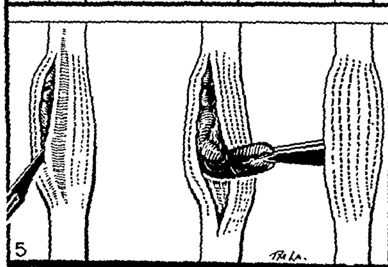

2a. *Complete fresh section of a nerve.*
b. *Freshening the edge with a razor.*
c. *Suturing the nerve ends.*




3a. *Old nerve section with neuroma, the proximal and distal ends.*
b. *Excision of neuroma with razor.*
c. *Suture of nerve.*




4. *Neuroma involving a portion of a lacerated nerve.*
a. *Separating the neuromatous from the normal portion.*
b. *Separation complete and excision of the neuroma.*
c. *Suture.*




5a. *Intraneural tumor (neurinoma), careful neurolysis and separation of tumor.*
b. *Careful dissection of tumor away from nerve bundles.*
c. *Following removal.*

*3.* In the presence of an old nerve injury, both the proximal and distal ends have undergone neuromatous degeneration requiring excision of the neuromatous portion before suture. The removal of this abnormal portion is done by sectioning segments of the nerve until normal bundles are obtained, both proximally and distally. Excision of the neuromatous portion may result in a gap of several centimeters between the proximal and distal end of the nerve. Under these circumstances, mobilization of the nerve by extensive dissection, transposition or flexion of a joint may be necessary in order to obtain end-to-end suture.

*4.* An example of partial section of a nerve resulting in a neuroma in continuity involving only a portion of the nerve is shown. Under these circumstances, a careful inspection of the surface of the nerve, in the region of the bulbous enlargement will reveal the presence of uninterrupted fibers. These should be carefully and sharply separated from the neuromatous portion by incising the epineurium and perineurium. After this portion has been separated from the normal fibers the neuroma may be excised and the nerve ends sutured with four or more sutures.

*5.* An example of a neurinoma within the substance of the nerve is shown. Such tumors usually grow between the bundles of the nerve. Under these circumstances, it is possible to incise the epineurium and expose the tumor, and with great care, separate the neoplastic tissue from the nerve bundles with minimal injury to the latter.

## Facial Nerve and Parotid Injuries

The facial or motor nerve to the face arises in the lower part of the pons and leaves the cranial cavity through the internal auditory meatus. It then lies in the facial canal of the petrous portion of the temporal bone making exit at the stylomastoid foramen to enter the parotid gland.

A sensory portion of the nerve transmits the sensation of taste from the anterior two-thirds of the tongue by the chorda tympani branch and the lingual nerve.

Traumatic lesions of the facial nerve are caused by lacerations of the face and may involve the trunk or branches in and about the parotid. High velocity shell fragment or bullet wounds may interrupt the nerve in and about the facial canal. Those interruptions which are peripheral to the stylomastoid foramen result in paralysis of all facial movements with drooping of the mouth, inability to wrinkle the forehead, or close the eye. Impairment of deep facial sensation may be noted.

Lesions in the facial canal may involve the chorda tympani branch and

thus abolish taste. When the peripheral portions are injured suture is indicated as soon as possible in order that the nerve elements may be identified in the fresh wound. A delayed secondary type of nerve suture is usually quite difficult and may be impossible to execute due to scar tissue.

The facial nerve consists of a motor and sensory portion, the latter being termed the nervus intermedius. After emerging from the lower border of the pons in the space between the olive and the inferior cerebellar peduncle, the nerve extends into the internal acoustic meatus, in company with the acoustic nerve. The motor part of the facial is the most medial and the acoustic nerve is the most lateral. In between, is the nerve of Wrisberg or the nervus intermedius. The facial nerve enters the facial canal and at first extends laterally, then it bends backwards and arches downward behind the tympanic cavity to the stylomastoid foramen. The geniculate ganglion is at the point where its direction changes. On emerging from the stylomastoid foramen, it courses laterally and anteriorly in the substance of the parotid gland. It divides into the pes anserinus which again subdivides into several branches supplying the muscles of expression, the occipitofrontalis muscle, the auricular muscles, the platysma, the posterior portion of the digastric and the stapedius muscles.

The branches of the facial include the nerve to the stapedius, and the tympani nerve while in the facial canal, the posterior auricular, the digastric, and stylohyoid, just as it comes out of the stylomastoid foramen, and in the face the temporal, zygomatic, buccal, mandibular and cervical branches. The chorda tympani nerve contains taste fibers from the anterior two-thirds of the tongue and secretory fibers to the salivary glands. The greater superficial petrosal nerve is a branch off the geniculate ganglion of the facial, and after leaving the facial canal through the hiatus, it runs in a sulcus on the anterior surface of the petrous portion of the temporal bone, beneath the trigeminal ganglion to the foramen lacerum. The greater superficial petrosal nerve is both sensory and glandular. Its section results in dryness of the nose on the same side and it has an inhibitory effect on the formation of the lacrimal secretion.

With lacerations of the lateral aspect of the face, it is best to obtain a repair as soon after injury as possible and while the wound is fresh. Under these circumstances, nerve twigs may be located by the use of electrical stimulation; because, although sectioned, they are still capable of being stimulated, thus making their position more easily identifiable. In certain instances the laceration may be fairly forward on the lateral aspect of the face, below and in front of the ear, so that not only the facial branches but also the parotid duct may be sectioned. Under these circumstances repair of the facial nerve fibers, as well as the parotid duct around a ureteral catheter is the method of choice, and again a fresh wound can be much more easily repaired than one that is several months old.

In *1* at *a* is the facial nerve and a diagrammatic representation of its branches supplying the various muscles which include posteriorly, the occipitalis, the posterior auricular; superiorly, the superior auricular and frontalis; anteriorly, the anterior auricular, the orbicularis oculi, the corrugator, the orbicularis oris, and the quadratus labii superioris, the risorius, the caninus, and the zygomaticus, as well as the mentalis, the quadratus labii inferiorus, the triangularis and the posterior belly of the digastric near the lower end of the ear and the platysma muscle of the neck.

In *2* at *a* the parotid gland and duct are diagrammatically shown. A small branch of the greater auricular nerve may be on the surface of the gland, extending to the lobe of the ear. The posterior auricular artery and vein and the superficial temporal artery and vein may be seen posteriorly and superiorly. The common facial, the frontal, and supra-orbital arteries and veins may be seen anteriorly.

In *3* the positions of usual types of laceration are shown at *a* and *b*. In some instances, the laceration as shown in *a* may cut only the main trunk of the nerve instead of the pes. A cut such as shown at *b* usually involves the parotid duct and also some of the finer twigs of the facial.

In *4* a laceration such as shown in *3a* is repaired. This includes suture of the various cut branches of the facial in the substance of the parotid gland.

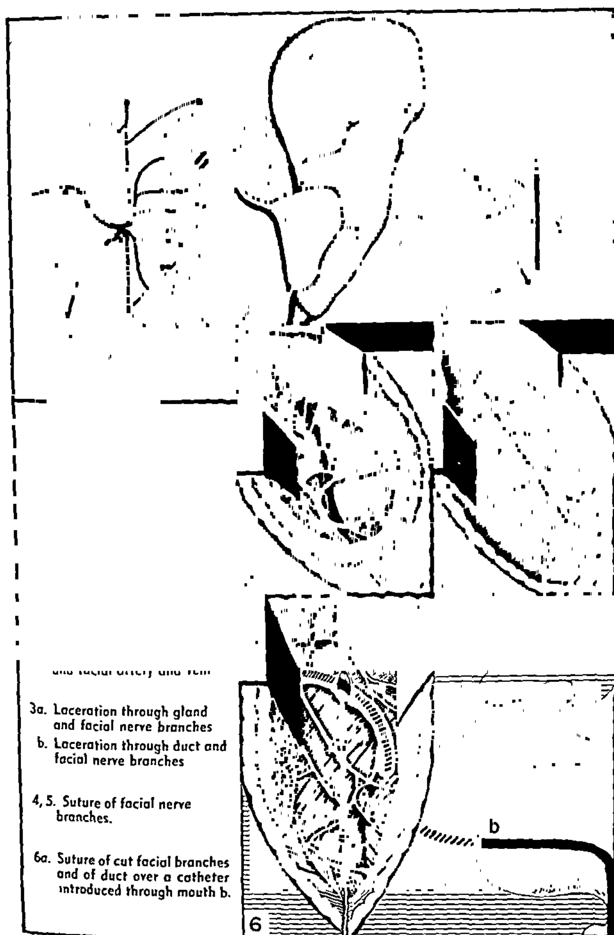
In *5* following suture, the superficial portion of the gland is approximated with interrupted sutures.

In *6* a laceration such as shown in *3b* is repaired by suturing the facial twigs, as well as the parotid duct around a ureteral catheter which is inserted into the duct through the mouth. The ureteral catheter is left in situ for four or five days and then it is removed. Sutures are taken to approximate the cut edge of the duct around the ureteral catheter, superiorly, inferiorly, anteriorly and posteriorly. Roentgen therapy to the parotid gland may be used in intractable parotid fistulae.

With lacerations of the face one should evaluate the extent of nerve involvement by a careful examination. It is important to note whether or not the frontalis contracts, whether or not the patient is able to close the upper lid and is able to elevate the angle of the mouth. The action of the platysma in many instances may not be easily discernible, particularly in the older individual. Depending upon the extent of the involvement, one then may look for the branches of the nerve supplying these various regions and suture them.

## Facial and Spinal Accessory Anastomosis

The spinal accessory or the hypoglossal may be used to anastomose to the facial to effect some degree of return of function to the musculature on the paralyzed side of the face The spinal accessory-facial anastomosis is preferred by the authors, but the same exposure will permit the use of either the 11th or the 12th nerve




3a. Laceration through gland and facial nerve branches
b. Laceration through duct and facial nerve branches

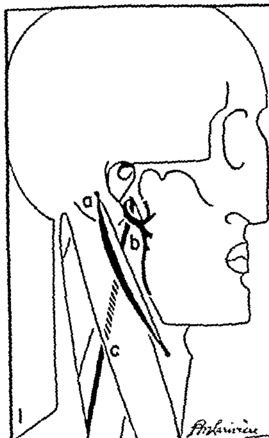
4, 5. Suture of facial nerve branches.

6a. Suture of cut facial branches and of duct over a catheter introduced through mouth b.

The spinal part of the accessory nerve originates from the motor cells of the anterior column of the gray substance of the spinal cord, as low as the fifth cervical segment. Its fibers pass up the side of the upper cervical cord to the lateral aspect of the medulla, and extend to the jugular foramen. In company with the 10th and 9th cranial nerves, the spinal accessory emerges from the cranial cavity through this foramen. In the majority of cases, the nerve passes in front of the internal jugular vein. It descends behind the digastricus and the stylohyoid muscles to the upper and internal aspect of the sternocleidomastoid, which it pierces, coursing through the substance of this muscle, and enters the posterior triangle of the neck, traversing it, obliquely downward and posteriorly, it ends in the deep surface of the trapezius muscle. It supplies twigs to the sternocleidomastoid and to the trapezius muscles, in company with branches from the cervical plexus and the second and third and fourth cervical nerves.

In *1* at *a* is shown the usual incision for exposure of the spinal accessory, the hypoglossal and the facial nerves. Such an incision extends from the mastoid to the thyroid cartilage neighborhood and around the angle of the jaw. After identifying the anterior border of the sternocleidomastoid, having already sectioned the platysma muscle, the deeper surface of the sternocleidomastoid is carefully dissected free from the surrounding tissues. Entering its deep surface at the junction of the upper third of the muscle and the angle of the jaw, the nerve can be seen extending down behind the posterior belly of the digastric muscle. It is of great help to have an electrical stimulator to stimulate the nerve. Its position immediately becomes apparent by the resultant contractions of the sternocleidomastoid muscle. The carotid sheath is also exposed under these circumstances and just below the digastric muscle, the external and internal carotid arteries, as well as the hypoglossal nerve and the ansa hypoglossi, are shown in *2* at *c*.

The facial nerve is dissected out on the posterior aspect of the parotid gland and in the space between the mastoid process and the parotid. It is best to expose the mastoid process by cutting some of the fibers of the sternocleidomastoid as shown at *a*, in *2*, with the dotted line. As the dissection is extended more deeply, the stylomastoid foramen comes into view. The facial nerve and the stylomastoid artery may be seen. A hook may be placed around the facial nerve which varies in size in this situation from patient to patient. In many instances, it is only half the size of the spinal accessory nerve to which it is sutured. The arterial bleeding from the stylomastoid foramen may be coagulated with the electrocautery unit after section of the facial at the stylomastoid foramen. The cut end of the nerve is then sutured with the spinal accessory which is looped around the posterior belly of the digastric muscle as shown in *3*. In many cases, with a cooperative patient, some degree of voluntary and emotional innervation of the face may return. Beginning evidence of return of function to the face may be seen at the end of four to six months




1a. Incision from mastoid to thyroid cartilage.
b. Facial nerve at stylomastoid.
c. Spinal accessory nerve.

2a. Dotted line cut attachment of sternocleidomastoid.
b. Posterior auricular artery and vein and great auricular nerve.
c. Retractor raising parotid gland and showing facial nerve on posterior belly of digastricus f.
d. Ligated superficial temporal vein and branch of great auricular nerve.
e. Ansa hypoglossi and artery to sternocleidomastoid.

3a. Facial-spinal accessory nerve sutured.
b. Cut end of the spinal accessory.
c. External carotid and hypoglossal nerve.

*1.* Incision from the middle of the sternocleidomastoid downward and posteriorly to the middle of the clavicle is adequate for exposure of the brachial plexus above the clavicle. In *1a* the posterior border of the sternocleidomastoid is identified, *b* is platysma and *c* the anterior border of the trapezius. *2.* The superficial nerves are shown and consist of *a*, the great auricular; *b*, the lesser occipital; and *c*, the transverse cervical nerves. The spinal accessory may also be found extending from the posterior border of the sternocleidomastoid toward the anterolateral aspect of the trapezius muscle (inferior to *b*). Cutaneous branches over the anterior shoulder are the anterior, middle and posterior supraclavicular nerves *d* and *e*.

*3.* The various muscles in this vicinity are noted. These include the splenius capitis at *a;* the levator scapulae at *b;* posterior scalene at *c;* the middle scalene at *d;* the anterior scalene at *e;* and the omohyoid at *f* Anteriorly, the sternocleidomastoid and posteriorly the trapezius muscles are shown.

*4.* A portion of the clavicle has been removed. The subclavius muscle may be seen at *a*, and the subclavian vein, artery and the brachial plexus are shown in that order with the plexus superiorly. It should be noted that the pectoralis minor muscle at *c* is immediately over the vein, artery and nerves. At *b* the cut pectoralis major is seen.

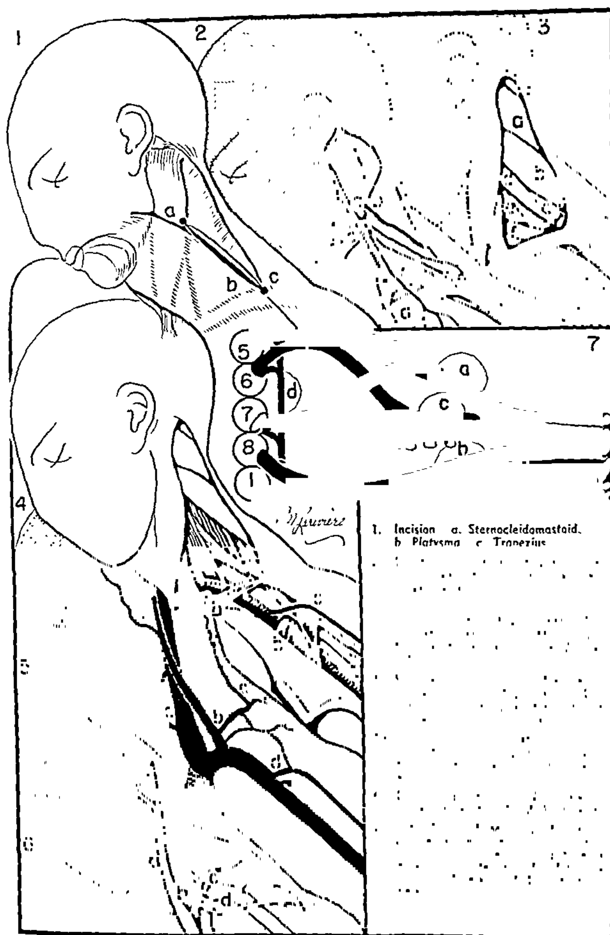
*5.* The veins in this vicinity are shown, the internal jugular at *a;* the external jugular at *b;* the posterior jugular and thoraco-acromial veins at *c;* with the cephalic vein emptying into the subclavian at *d.*

*6.* The arteries in this neighborhood include the common carotid at *a;* the thyrocervical trunk at *b;* the vertebral at *c;* the subclavian at *d.*

The plan of the brachial plexus is shown in *7.* The brachial plexus arises *from the 5th, 6th, 7th, 8th cervical and 1st dorsal spinal nerves.* The lateral, medial and posterior cords of the brachial plexus are shown at *a*, *b*, and *c* respectively. The posterior cord of the brachial plexus, *c*, ends in the smaller axillary and larger radial nerves. From the posterior cord also are given off three branches which are the upper subscapular, the thoraco-dorsal and the lower subscapular nerves. With a union of the lateral and medial cords the following nerves are given off from above downward, the musculocutaneous, the median, the ulnar, the medial antebrachial cutaneous and the medial brachial cutaneous nerves. The long thoracic nerve arises from the 5th, 6th and 7th anterior cervical roots and supplies the anterior serratus muscle, *d.*

The supraclavicular exposure of the brachial plexus reveals the anterior rami *of the lower cervical spinal nerves and the 1st thoracic nerve* which help to form the lateral, medial and posterior brachial plexus cords. The cords are seen best after section or excision of the clavicle and exposure of the plexus below the clavicle.

The supraclavicular exposure of the brachial plexus may be carried out by incision of the skin and platysma from about the middle of the posterior


1
2
3
4
5
6
7
8
a
b
c
d
1. Incision a. Sternocleidomastoid. b Platysma c Trapezius

head of the sternocleidomastoid to the middle of the clavicle. On entering the posterior triangle of the neck, the position of the anterior scalene and transverse processes of lower cervical vertebrae may be ascertained by palpation. The retraction of the lateral border of the anterior scalene will directly expose the outgoing anterior rami from the brachial cords. These rami are found between anterior and middle scalene muscles. For exposure of anterior scalene also see Plates 317 and 318.

### *Supra and infraclavicular exposure of the brachial plexus*

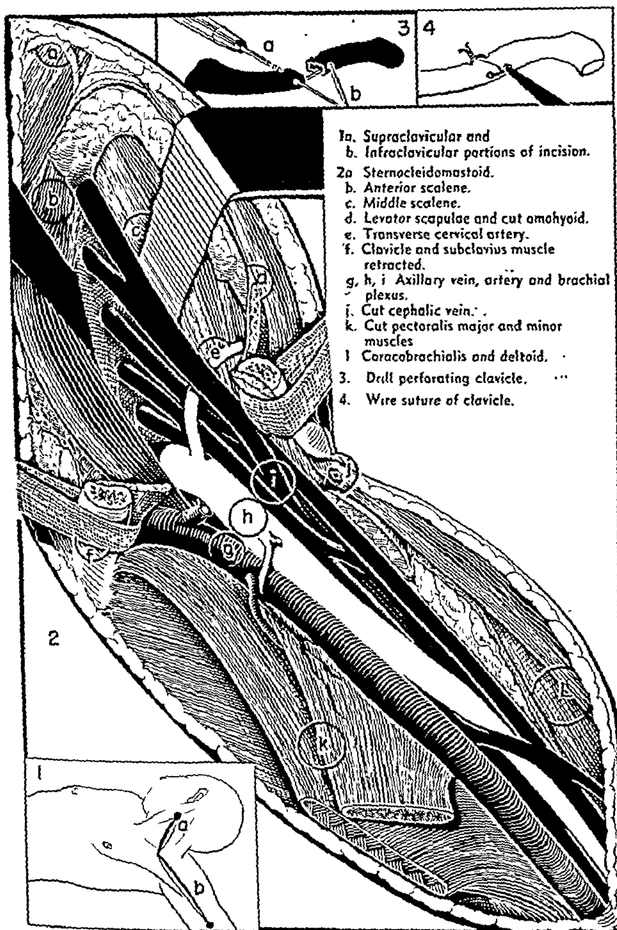
▶

*1.* The plan of incision is shown. At *a* the incision extends from the middle of the posterior border of the sternocleidomastoid muscle down and posteriorly to the middle of the clavicle. From there the incision extends as shown at *b* over the anterior axillary fold to the medial aspect of the arm.

*2.* The brachial plexus and the subclavian vessels have been exposed after incision of the clavicle and retraction of the ends. At *a* the posterior border of the sternocleidomastoid is shown; *b* represents the anterior scalene muscle and *c* is the middle scalene; *d* is the levator scapulae muscle and the cut end of the omohyoid; *e* is the transverse cervical artery lying on the middle and posterior scalene muscles; *f* is the cut clavicle retracted to expose the brachial plexus and subclavian vessels; *g*, *h* and *i* are axillary vein, axillary artery and the brachial plexus; *j* is the cut end of the cephalic vein; *k* is the pectoralis minor immediately underlying the pectoralis major and these have both been cut; *l* represents the coracobrachialis and deltoid muscles.

After incision of the skin, the subcutaneous fat, and the platysma above the clavicle, several superficial veins may have to be doubly ligated and cut. These include the posterior jugular if present, the external jugular above the clavicle and the cephalic vein below the clavicle. The dissection is extended until the clavicle is completely exposed superiorly, inferiorly, and posteriorly and cut with a Gigli saw. The subclavius muscle, which is immediately underneath the clavicle, may also be sectioned at this juncture. The vein, artery, and nerves are now exposed and one may dissect the nerves upward toward the junction of the anterior and middle scalene muscles and downward toward the axilla. In the axillary portion of the exposure one must, as a rule, cut the pectoralis major and minor muscles, which, along with the clavicle, are resutured at the conclusion of the operative procedure

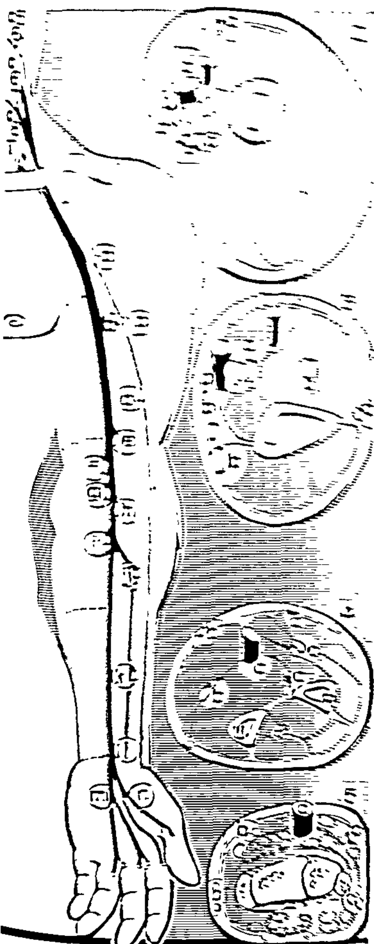
*3* Suture of the clavicle with wire is performed. A drill is used to make a hole in the bone. The hole in the clavicle may be made from above downward in such a manner that a wire suture may be passed as shown in *j*, the wire entering the hole in the distal portion superiorly and running through the bone and out through the hole on the inferior aspect of the clavicle. Thence it is threaded through the inferior hole of the proximal portion to the superior hole of the proximal portion. It is fastened by turning the wire ends in such a manner as to get a tight approximation of the bone. After cutting off the excess wire, the twisted portion may be carefully pulled inferiorly and tucked into the hole in the clavicle Steel wire may be used.


3
4
a
b
1
2
a
b
c
d
e
f
g
h
i
k
1a. Supraclavicular and
b. Infraclavicular portions of incision.
2a Sternocleidomastoid.
b. Anterior scalene.
c. Middle scalene.
d. Levator scapulae and cut omohyoid.
e. Transverse cervical artery.
f. Clavicle and subclavius muscle retracted.
g, h, i Axillary vein, artery and brachial plexus.
j. Cut cephalic vein.
k. Cut pectoralis major and minor muscles
l Coracobrachialis and deltoid.
3. Drill perforating clavicle.
4. Wire suture of clavicle.

The musculocutaneous nerve has its origin from the 5th, 6th and 7th cervical nerves. It arises from the lateral brachial cord at the lower border of the insertion of the pectoralis minor muscle. It pierces the coracobrachialis muscle high up in the axilla and then it extends between the biceps and brachialis muscles to the lateral aspect of the arm. It supplies the coracobrachialis, *a*, the biceps, *b* and *c*, and the brachialis muscles, *d*. Just above the elbow it pierces the deep fascia of the arm, lateral to the biceps tendon. It continues into the forearm as the lateral antebrachial cutaneous nerve.

The median nerve arises from the 6th, 7th, and 8th cervical and 1st thoracic nerves. It is formed by two roots, one from the lateral and another from the medial cord of the brachial plexus. These two roots embrace the axillary artery and unite either in front of or lateral to the same. The artery, as well as the median nerve, is found in front of the teres minor and major muscles and the latissimus dorsi. Beyond, the median nerve extends between the coracobrachialis and the long head of the triceps. Further distally, it is just medial to the junction of the biceps and brachialis muscles. It lies on the brachialis muscle, between the biceps and brachialis. It extends to the elbow under the lacertus fibrosus in a position medial to the brachial artery. In the forearm, near the elbow, it gives off several muscular branches, then it extends through the substance of the pronator teres. It passes through the two heads of the pronator teres, and in this situation, the deep head of the pronator separates the nerve from the brachial artery. It descends under the flexor digitorum sublimis lying on the flexor digitorum profundus. About 2 inches above the transverse carpal ligament it becomes more superficial and it is situated between the tendons of the flexor digitorum sublimis and the flexor carpi radialis. It is lateral to the tendon of the palmaris longus at the palm-wrist junction. It then dips behind the transverse carpal ligament into the palm of the hand.

At *e* the supply to the pronator teres; at *f* the branch of the flexor carpi radialis; at *g* and *h* the flexor digitorum sublimis; at *i* the branches to flexor digitorum profundus are given off. The branches of the anterior interosseous supplying the flexor pollicis longus, flexor digitorum profundus and the pronator quadratus muscles are represented at *j*, *k* and *l*. The palmar branches are shown at *m* and *n*. Aside from the cutaneous supply to the thumb, index, long, and one-half of the ring fingers, as well as the distal phalanx and a half of the index and long fingers on the dorsal surface, the median also supplies branches to the lateral 2½ lumbricales and to the flexor opponens pollicis. In the cross sections *2*, *3*, *4* and *5*, the position of the median and musculocutaneous nerves is given In *2*, the median nerve is found anterior and medial to the axillary artery and veins, immediately between the coracobrachialis and teres major muscles. The musculocutaneous is in the substance of the coracobrachialis muscle and lateral and anterior to the median nerve. In *3* the median nerve *a* is on the medial aspect of the arm, immediately medial to the brachial vessels and in the space between the biceps and brachialis muscles. The musculocutaneous *a* has now pierced the coracobrachialis muscle and is in a position between the biceps and the



[illegible]

3. a. Median, musculocutaneous[illegible] brachial artery and veins
b. Ulnar nerve, medial ante[illegible] brachial cutaneous, basilic vein
c. Radial nerve

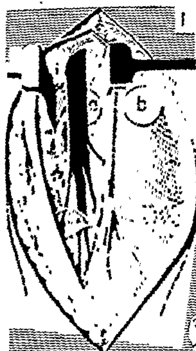
4. a. Median and anterior in[illegible] nerves
b. Ulnar nerve, basilic vein
c. Deep radial, dorsal antebrachial [illegible] nerves, superficial radial.

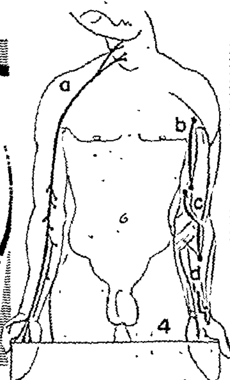
brachialis extending down toward the lateral aspect of the arm. In 4, which is a section in the *upper third of the forearm, we now find* the median nerve between the flexor digitorum sublimis and flexor digitorum profundus group of muscles at *a*. It has already given off its anterior interosseous branch which is on the anterior aspect of the interosseous membrane accompanied by the interosseous artery. The lateral antebrachial cutaneous nerve may be seen at *a*, immediately under the skin on the *anterolateral aspect of the forearm*. In 5, the median nerve is in a cross-sectional preparation just above the wrist and we find the nerve lateral to the tendon of the palmaris longus. It is covered by skin and fascia and it is also situated between the tendons of the flexor digitorum sublimis and flexor carpi radialis muscle.

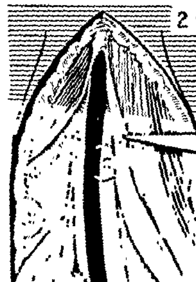
## Exposure of the median nerve in high arm, elbow and wrist

In 3 the exposure of the median nerve through an incision at 4b is shown. The incision is placed on the medial aspect of the arm, and beginning in the axilla just posterior to the anterior axillary fold, it extends down the arm for 5 to 6 inches. After going through the skin and subcutaneous fascia, the crossing fibers of the pectoralis major may be seen at the upper border of the incision. *The median nerve, the medial brachial cutaneous, the ulnar nerve,* and the medial antebrachial cutaneous nerve and brachial artery are all in a connective tissue compartment between the coracobrachialis and the teres major superiorly, and anteriorly, and the biceps brachialis inferiorly and anteriorly and the triceps posteriorly. One may be able to feel the pulsations of the brachial artery as the exposure proceeds. After incising the outer lining of the connective tissue compartment, enclosing the vessels and the nerves, the median is found to be one of the two of the largest nerves and is the most anterior in position. As the dissection is extended *superiorly*, the musculocutaneous nerve may be seen piercing the coracobrachialis muscle as shown just a little above c. The positions of the coracobrachialis and the triceps are shown at *d* and *b*. The brachial vessel is seen at *e* and *f* is the brachialis muscle; *g* is the biceps. As the dissection extends downward toward the elbow, *the ulnar nerve is seen to deviate more* and more posteriorly, while the median nerve remains in a more anterior position and seems to extend somewhat laterally toward the center of the elbow joint. The nerve may be in a position *lateral to the brachial artery superiorly*, and it may be found to cross the brachial artery to its medial aspect inferiorly.

In 2 the dissection of the median nerve in the incision shown at 4c is pictorially visualized. The median nerve may be found after incising the skin and subcutaneous fascia in a position between the biceps tendon and *the brachialis laterally and the triceps posteriorly* It is found to lie on the brachialis muscle. On its lateral aspect is the brachial artery *a*. It may be followed toward the elbow, posterior to the lacertus fibrosus. At the elbow, the nerve extends between *the two heads of the pronator teres c* and as this takes place, the deeper head of the pronator teres separates the artery from the nerve. In the more inferior portion of the antecubital fossa, the nerve is surrounded by the pronator teres medially and the biceps and brachialis muscles laterally *e* The triceps is *b* and just a little above it is the ulnar nerve in the background extending posteriorly to the medial epicondylar groove.

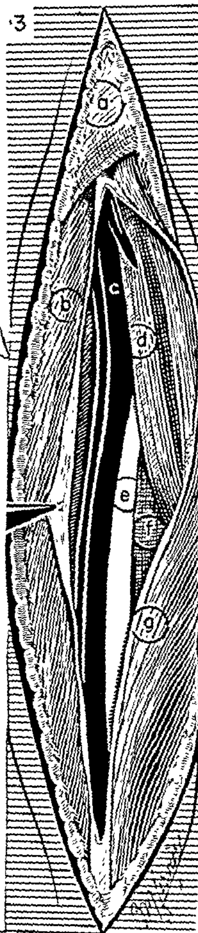






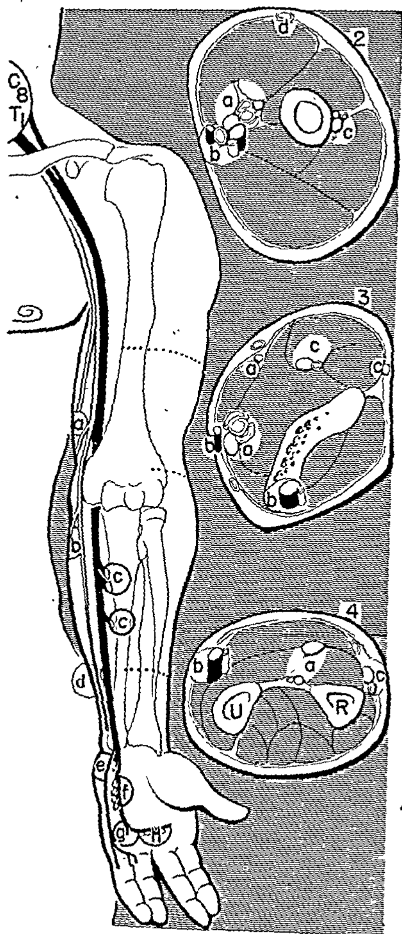



1. Incision 4d.
   a. Median nerve at the wrist.
   b. Abductor pollicis brevis.
   c. Volar arch and palmar fascia. Retractor holding annular ligament at wrist.
2. Incision 4c.
   a. Median nerve and brachial artery.
   b. Triceps
   c. Pronator teres.
   d. Median nerve splitting the pronator.
   e. Biceps and brachialis, median nerve on brachialis.
3. Incision 4b.
   a Pectoralis major
   b Triceps.
   c Median, musculocutaneous entering
   d Coracobrachialis.
   e Brachial artery.
   f. Brachialis muscle
   g Biceps: Medial to median nerve are medial brachial cutaneous and ulnar nerves
4. Position of incisions.

In *1* the exposure of the median nerve at the wrist as shown at *4d* is carried out. At the wrist, the median nerve is found just lateral to the palmaris longus tendon and between the flexor carpi radialis and the flexor sublimis tendons. It dips under the transverse carpal ligament, and then it extends into the palm and immediately divides into four or five terminal branches. In the palm, after extending the incision through the palmar fascia, the branches of the median nerve can be found with ease in a position superficial to the sheath of the deep and superficial tendons of the fingers. Dissection proceeds toward the digits The volar arch may be seen anterior to the median nerve branches. For good exposure, this may have to be doubly ligated and cut. Branches of the median in the palm are quite large and can be easily sutured if the necessity arises, usually with two silk sutures. The median nerve is shown at *a* and annular ligament being retracted; *b* is abductor pollicis brevis; *c* is the volar arterial arch.

## Ulnar, medial antebrachial cutaneous, and medial brachial cutaneous nerves and cross sections ▶

The ulnar nerve arises from the medial cord of the brachial plexus in the axilla and it gets its fibers from the 8th cervical and the 1st thoracic spinal nerves. In the axilla it may be found medial to the brachial artery and somewhat posterior and medial to the median nerve, lying on the teres major and latissimus dorsi muscles. Just below the posterior axillary fold, it is on the medial aspect of the long head of the triceps and extends down to the elbow, first in close proximity to the median nerve and brachial artery, but at the junction of the middle and lower thirds of the arm, it deviates posteriorly, having pierced the medial intermuscular septum and thereafter, extending toward the epicondylar groove. It enters the forearm between the two heads of the flexor carpi ulnaris After giving off branches to the flexor carpi ulnaris, *c*, and the elbow joint, it extends under cover of the flexor carpi ulnaris, over the flexor digitorum profundus, *d*, toward the wrist. In the upper half of the forearm, it is covered by the flexor carpi ulnaris muscle; whereas, in the lower half, the nerve is superficial, being covered by skin and subcutaneous fascia and lying immediately lateral to the tendon of the flexor carpi ulnaris muscle. The ulnar artery runs next to the ulnar nerve, at the junction of the upper and middle third of the forearm; thereafter, the ulnar artery is in a position just lateral and anterior to the ulnar nerve. About 5 cms above the wrist the ulnar nerve gives off a dorsal cutaneous branch which is distributed on the posterior aspect of the little and ring fingers and the corresponding portion of the dorsum of the hand The ulnar nerve crosses under the transverse carpal ligament, just lateral to the insertion of the flexor carpi ulnaris into the pisiform bone In the hand it divides into a superficial and deep branch. The superficial branch supplies the palmaris brevis and the sensory distribution of the ulnar side of the hand, *e*, whereas the deep branch supplies the three small muscles of the little finger, flexor, adductor and opponens digiti quinti, the interossei, the third and fourth lumbricales, adductor pollicis and the medial head of the flexor pollicis longus, *f*, *g*, *h*




Ulnar Nerve (distribution)

1a. Medial brachial cutaneous.
b. Medial antebrachial cutaneous.
c. Flexor carpi ulnaris and flexor digitorum profundus.
d. Dorsal cutaneous.
e. Superficial branch.
f. Deep branch.
   Palmaris brevis.
   adductor, opponens, flexor } digiti quinti
g. 3rd and 4th lumbricales.
h. Interossei.

2. Cross section midarm.
a. Median and musculocutaneous nerves with brachial artery and veins.
b. Ulnar, medial antebrachial cutaneous, basilic vein and ulnar collateral artery.
c. Radial nerve and deep brachial artery.
d. Cephalic vein.

3a. Median nerve, brachial artery and veins, medial antebrachial cutaneous, musculocutaneous.
b. Ulnar nerve, recurrent ulnar artery.
c. Radial nerve, deep brachial artery and superficial radial nerve.

4a Radial.
b. Ulnar nerve and artery.
c. Superficial radial nerve and vein.

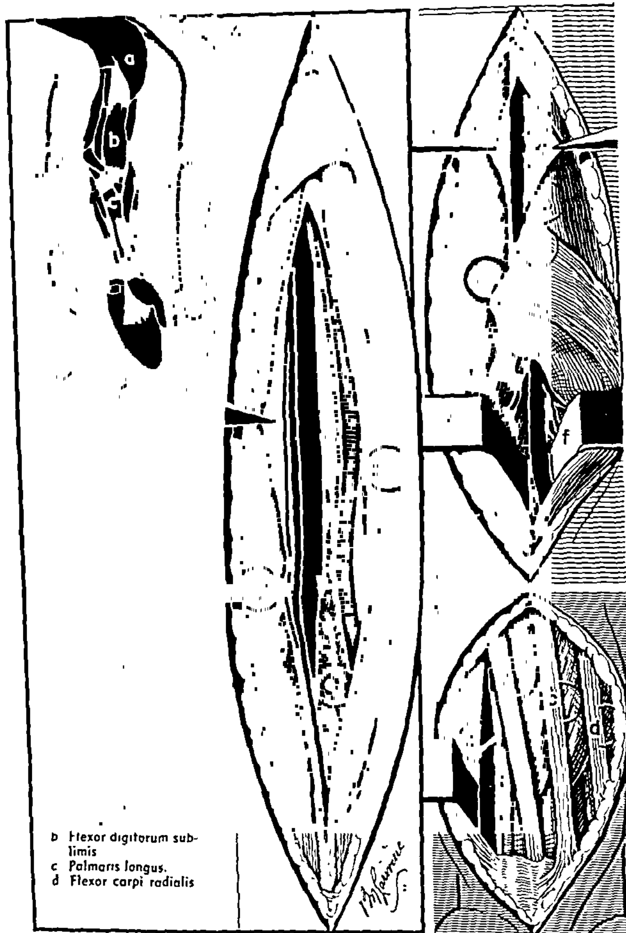
The position of the ulnar nerve may be noted in the cross-sectional diagrams of the upper limb. In *2* the ulnar nerve is found in connective tissue between the biceps and the triceps and the brachialis muscle. It is in a position posterior to the median nerve and it is immediately medial to the brachial vessels. At the elbow the ulnar nerve may be seen in the epicondylar groove at *3*, in *b*, accompanied by the recurrent ulnar artery. The medial antebrachial cutaneous nerve is now on the anterior aspect of the elbow joint in close proximity to the median nerve and it extends peripherally to supply the anterior and medial aspect of the forearm. In the epicondylar groove the nerve is in the vicinity of the triceps insertion and the anconeus muscle. In *4* the ulnar nerve is lateral to the tendon of the flexor carpi ulnaris and is accompanied by the ulnar artery, which is lateral and anterior to the nerve.

## Exposure of the ulnar nerve in high arm, elbow and wrist

▶

In *4* incision *1a* is enlarged upon. In the upper two-thirds of the arm, incision for exposure of the ulnar nerve is placed on the medial aspect of the arm beginning in the axilla, in a plane halfway between the anterior and the posterior axillary folds, and extending down toward the medial aspect of the elbow joint. After the skin and subcutaneous tissue has been incised, the ulnar nerve and the medial antebrachial cutaneous nerves are found in the connective tissue compartment between the coracobrachialis and triceps muscles; and between the biceps and the triceps more peripherally. In the axilla it is bounded by the latissimus dorsi, and higher, its medial boundary is the teres major muscle. The ulnar nerve is smaller than the median and the pulsations of the brachial artery can be felt between the two. About the junction of the middle and lower thirds of the arm, the ulnar nerve begins to veer posteriorly, after piercing the medial intermuscular septum. It is crossed by the medial antebrachial cutaneous which extends toward the anterior aspect of the elbow to supply the forearm. The ulnar nerve is in juxtaposition to the triceps muscle in the lower third of the arm, and can be easily seen or felt after incision of the fascial lining of this muscle.

In *5* the exposure of the ulnar nerve at the epicondylar groove may be accomplished through an incision as shown in *1b*. This incision is extended through the skin and superficial fascia, making sure that the extremity is rotated so as to make the region of the epicondylar groove easily accessible. Above the epicondylar groove, near the medial epicondyle, the ulnar nerve may be easily palpated and can be exposed by incising the fascia of the triceps muscle The nerve is easily separated from the surrounding tissues and in order to make the operative procedure as bloodless as possible, the separation should involve mainly the nerve immediately behind the ulnar collateral artery By careful dissection along the epineurium, this can be accomplished. The nerve can be followed down to the epicondylar groove where it is surrounded by a tough fascial lining This may be incised or cut with scissors, particularly if the nerve is easily separable from the surrounding connective tissues. At times there may be adhesions between the nerve and the epicondylar groove, in which case the dissection must proceed very carefully, so as not to injure the nerve As the ulnar is exposed in the epicondylar


a
b
f
c
d
b Flexor digitorum sublimis
c Palmaris longus.
d Flexor carpi radialis

groove, a small twig which extends to the elbow joint may be sacrificed. In the middle of the epicondylar groove is another large branch which supplies the flexor carpi ulnaris muscle. Section of this nerve may be performed since other lower branches supply the same muscle. If possible, it should be saved. This can be done by separating the bundle from the main trunk of the nerve by neurolysis. Below the elbow the main trunk of the nerve may be dissected free between the two heads of the flexor carpi ulnaris. In *5* the ulnar nerve and the superior ulnar collateral artery may be seen at *a*; *b* is the brachial muscle; *c* is the pronator teres; *d* is the triceps; *e* and *f* represent the flexor carpi ulnaris and anconeus muscles medially and the flexor carpi ulnaris laterally. In *6* is the exposure seen in *1c*. The ulnar nerve and the ulnar artery are found immediately lateral to the tendon of the flexor carpi ulnaris. At *a* the dorsal cutaneous branch of the ulnar is given off about 5 cm. above the wrist. The tendon of the flexor digitorum sublimis is seen at *b*; *c* is the palmaris longus; *d* is the flexor carpi radialis.

## Ulnar nerve transposition for tardy ulnar neuritis ▶

Tardy ulnar neuritis was first described by Panas and may be associated with a valgus deformity of the elbow due to injury of the lateral condyle in childhood with improper union or it may be produced by involvement of the nerve in the epicondylar groove, by scar and lacerations, arthritic changes and minor injuries. The adhesions occurring between the nerve and the surrounding tissues may result in traction with chronic irritation and eventual ulnar dysfunction. The condition may manifest itself many months or years after the initial trauma which may have resulted in scarring or traction. This condition is remedied by anterior transposition of the ulnar nerve. If the nerve is found to be undergoing neuromatous degeneration with much scarring, a neurolysis may also be indicated. It is important to intervene before marked changes occur in the hand. These changes are characterized by progressive atrophy of muscles in the ulnar distribution. The adductor pollicis, the interossei and the medial lumbricales 2 or 3 are involved. A flexion deformity of the little and ring fingers, poor grip and flattening of the palm from atrophy with a severe involvement of the hypothenar eminence are seen. There may be sensory loss in the form of hypesthesia and sudomotor paralysis in the ulnar distribution

In the accompanying illustration the management of transposition of the ulnar is shown. In *4* the type of incision used for this purpose is outlined. In *1* the exposure of the ulnar nerve and the proposed area of transposition are shown. The dotted line *abc* is the position of the transposed nerve whereas the dotted line *a* to *c* is the position of the ulnar nerve behind the epicondylar groove seen at *b*. After the incision has been made, the medial portion of the skin flap is reflected off the epicondylar groove and medial epicondyle by carrying out the dissection between the antebrachial fascia and the subcutaneous connective tissue layer of the skin By positioning the extremity the medial posterior aspect of the elbow neighborhood can be brought into good view. The ulnar nerve can be palpated above the medial epicondyle as a tough cord-like structure immediately under the brachial fascia and the triceps muscle fibers. An incision into the brachial fascia will expose the nerve




1a, b, c. Position of transposed ulnar nerve.
a-c. Extent of exposure of ulnar nerve.
d. Medial epicondyle.

2a. Ulnar nerve dissected.
Articular branch cut.
b. Undermining subcutaneous tissue.
c. Ulnar nerve dissected between heads of flexor carpi ulnaris.
d. Medial epicondyle.
e. Ulnar nerve.
f. Flexor carpi ulnaris and pronator teres.

3a. Ulnar nerve.
b. Subcutaneous tissue sutured over ulnar nerve.
c. Skin and subcutaneous fat.
d. Closure of antebrachial fascia.

4. Incision for ulnar transposition.






which can then be dissected free from the surrounding tissues. It is best to dissect the nerve from the surrounding blood vessels. If this is done, there is less bleeding during the procedure. The nerve is then followed down into the epicondylar groove and past the epicondylar groove. Exposure may be obtained by using scissors or a knife. In *2* the ulnar nerve has been exposed above and below the elbow. Its articular branch at *a* is cut. This is almost always necessary. Its muscular branches to the flexor carpi ulnaris are preserved. At *b* the subcutaneous tissue is being undermined anterior to the muscles of the antecubital region. At *f* the flexor carpi ulnaris and the pronator teres muscles are showing, the pronator teres being just below *d*. The ulnar nerve is seen entering the flexor carpi ulnaris muscle at *e*. At times it may be necessary to cut the muscle fibers of the flexor carpi ulnaris in the region of *f* transversely in order to obtain a loose transposition of the nerve without irregularities of contour of tissues.

In *3* the ulnar nerve has been transposed to the anterior aspect of the elbow and the subcutaneous tissue in front of the elbow is being sutured over the nerve seen at *a*; *b*, the undermined subcutaneous tissue and antebrachial fascia is shown. At *c* is the skin and subcutaneous fat and at *d* is the antebrachial fascia being sutured over the nerve. With good exposure the anterior transposition does not result in kinking or undue tension of the nerve.

In many instances there is improvement in the clinical condition of the patient a few days after the transposition. However, recovery from atrophic changes in the hand takes a long time and may never be complete, particularly in the more advanced cases. The increasing disability is kept from advancing after the transposition. In the untreated cases this disability eventuates in a claw hand.

### Axillary and radial nerves and cross sections

▶

The axillary nerve arises from the posterior cord of the brachial plexus and its fibers are derived from the 5th and 6th cervical nerves. It is posterior to the axillary artery and in front of the subscapularis muscle. At the lower border of this muscle it passes through a quadrilateral space, in company with the posterior humeral circumflex artery. It divides into anterior and posterior branches. Both of these branches supply the deltoid and the teres minor muscles. The posterior branch also gives off the lateral brachial cutaneous nerve which supplies the lateral aspect of the upper arm, *a*. The quadrangular space through which the nerve passes in company with the posterior humeral circumflex vessel is bounded by the teres minor and subscapularis above, the teres major below, the triceps medially and the surgical head of the humerus laterally

*Radial Nerve.* The radial nerve is a branch of the posterior cord of the branchial plexus. Its fibers are derived from the 5th, 6th, 7th, 8th cervical and 1st thoracic nerves. Its origin is posterior to the axillary artery. It courses in front of the latissimus dorsi and teres major tendons. It then winds around the humerus, along the radial groove, in company with the deep brachial artery, between the medial and lateral heads of the triceps

1a. Axillary, muscular and lateral brachial cutaneous branches.

Radial Nerve.

b. Triceps.

c. Posterior brachial cutaneous.

d. Lateral brachial cutaneous

e. Brachioradialis and extensor carpi radialis longus

f. Posterior antebrachial cutaneous.

g. Posterior interosseous, extensor carpi radialis brevis and supinator.

h. Extensors digitorum, digiti quinti and carpi ulnaris.

i. Abductor pollicis longus, extensor pollicis longus and brevis.

j. Dorsal digital cutaneous.

2a Median, musculocutaneous

b. Medial antebrachial cutaneous, brachial artery and veins, ulnar nerve

c. Radial nerve and deep brachial artery.

d Cephalic vein.

3a. Median nerve, brachial artery and veins, musculocutaneous nerve.

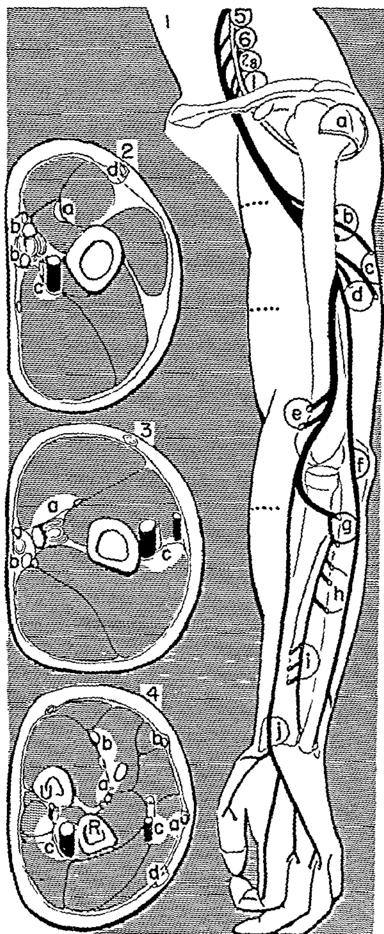
b Medial antebrachial cutaneous, basilic vein, and ulnar nerve.

c Radial, dorsal antebrachial cutaneous and deep brachial artery

4a Median nerve, anterior interosseous nerve and artery, cephalic vein.

b Ulnar nerve, basilic vein

c Deep radial, superficial radial



muscle. In the middle third it perforates the intermuscular septum and courses down between the brachialis and brachioradialis muscles, and in front of the head of the radius it divides into deep and superficial branches. The deep branch extends between the two planes of the fibers of the supinator and winds around the upper end of the radius to the posterior aspect of the forearm. It supplies the extensor muscles of the hand and it further extends as the dorsal interosseous nerve on the dorsal aspect of the interosseous membrane to the posterior portion of the carpus. The superficial radial nerve extends along the lateral and posterior aspect of the forearm to the skin of the dorsum of the hand. It supplies the thumb, index, long fingers and one-half of the ring finger and corresponding portion of the dorsal surface of the hand.

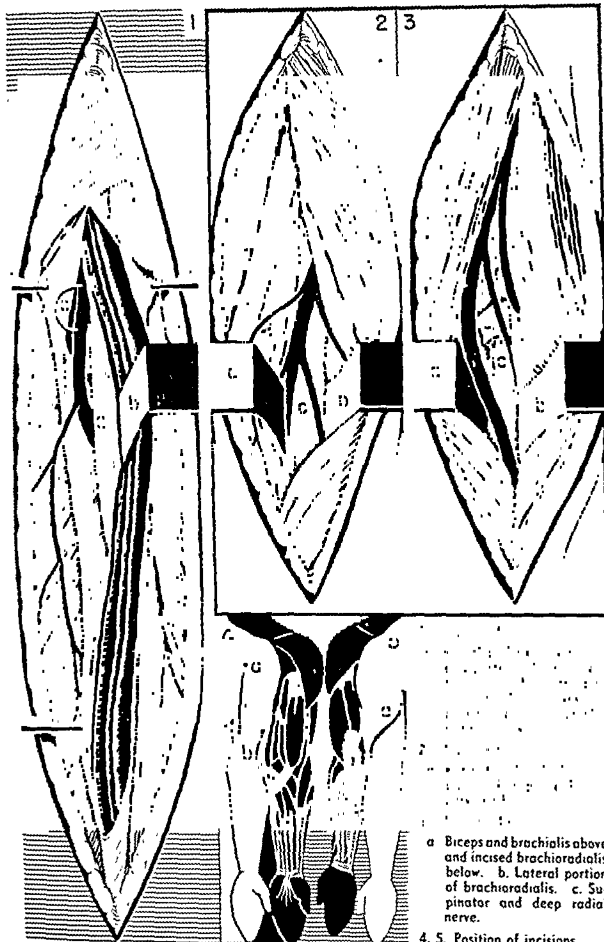
The branches of the radial include *b* to the triceps, *c* posterior brachial cutaneous, *d* lateral brachial cutaneous, *e* brachioradialis and extensor carpi radialis longus and anconeus, *f* posterior antebrachial cutaneous, *g* posterior interosseus, extensor carpi radialis brevis and supinator, *h* extensor digitorum, extensor digiti quinti and extensor carpi ulnaris, *i* abductor pollicis longus, extensor pollicis longus and brevis, extensor indicis proprius, *j* dorsal digital cutaneous nerves.

## Exposure of radial nerve near axilla, posterior arm and elbow

▶

In *1* the radial nerve is exposed while it courses on the medial aspect of the arm, near the axilla as shown in *4a* The incision for such exposure is placed halfway between the anterior and posterior axillary folds, the upper end of the incision extending high up into the axilla. After incising the skin and subcutaneous tissue the space between the coracobrachialis anteriorly and the latissimus dorsi, teres major, and the triceps posteriorly, is carefully explored for the axillary artery and branches of the brachial plexus. The radial nerve is the most posteriorly placed structure and it is usually the largest in the group. Its direction is laterally and posteriorly toward the humerus High up in the arm, immediately under cover of the pectoralis major, the nerve is found to extend posterior to the brachial vessels. The axillary nerve may also be visualized by dissecting upward into the axilla to the posterior cord of the brachial plexus. The axillary nerve extends posteriorly between the subscapular and teres minor muscles on its superior aspect, with the teres major on its inferior aspect, the long head of the triceps medially, and the surgical neck of the humerus laterally, in company with the deep humeral circumflex artery. As the radial nerve is followed toward the humeral groove, it may be seen to give off muscular branches to the triceps. It is found between the medial and the lateral heads of the triceps muscle *1a* shows the radial and axillary nerves and the posterior brachial cutaneous; *b* shows retraction of the median and ulnar nerves, and the biceps and coracobrachialis muscles, exposing the brachial artery

In *2* exposure of the radial nerve while it is in the humeral groove is shown, as outlined in *5a* After incision of the skin and subcutaneous tissue the body of the triceps muscle is incised along the length of its fibers, until the humerus can be felt The nerve in the humeral groove may now be palpated and rolled under the finger With careful retraction of the brachialis and the triceps




a Biceps and brachialis above and incised brachioradialis below. b. Lateral portion of brachioradialis. c. Supinator and deep radial nerve.

4, 5. Position of incisions.

medially as shown at *a*, and the triceps laterally as shown at *b*, the radial nerve, *c*, is exposed. In its course through the groove, it gives off several branches to the triceps, as well as cutaneous branches which become superficial and supply the posterior aspect of the forearm (posterior antebrachial cutaneous).

In *3* the radial nerve is exposed on the lateral aspect of the arm and forearm. In this situation, the nerve may be involved in callus with lower third humeral fractures and anterior dislocation of the head of the radius. The latter involves mainly the deep radial branch. The position of the incision is *shown in 4b. After incision of the skin and subcutaneous tissue, the line of* cleavage between the brachioradialis and the brachialis muscles is made on the lateral aspect on the arm and elbow. In the depth of the line of cleavage, one finds the radial nerve. Two or three branches are given off in this situation supplying the brachioradialis muscle. Dissection may be extended inferiorly to the antecubital fossa. At *a* the biceps and brachialis are shown. At *b* the brachioradialis is retracted laterally; at *c* the supinator muscle is shown, which is pierced by the deep radial as it swings around toward the dorsal aspect of the radius and the dorsal aspect of the forearm.

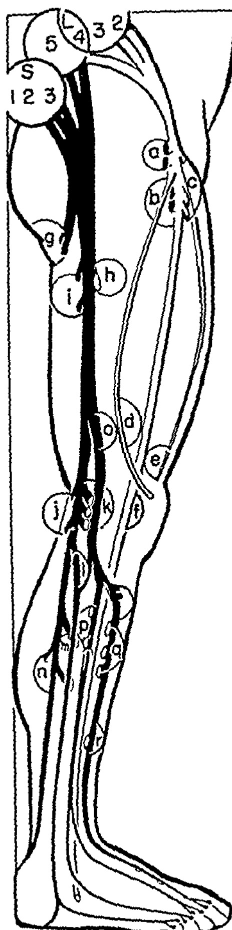
## Femoral and sciatic nerves

▶

The femoral nerve arises from the 2nd, 3rd, and 4th lumbar nerves. It descends between the psoas major and the iliacus It runs to the thigh behind the inguinal ligament, under which a portion of the psoas major separates the femoral artery from the nerve. About 2 cm. below the inguinal ligament it begins to divide into its muscular and cutaneous branches. The muscular branches include the nerve to rectus femoris; *a*, to vastus lateralis, and vastus intermedius, *b*, *c*, pectineus, sartorius and vastus medialis and *e*, the lower parts of the quadratus femoris muscle. The cutaneous branches supply the medial and intermediate cutaneous nerves of the thigh and the saphenous nerve which supplies the medial and anterior aspect of the leg and foot *d*, *e*, *f*.

The sciatic nerve has two terminal branches, the tibial and the peroneal. The sciatic nerve arises from the 4th and 5th lumbar and the first three sacral anterior roots. It leaves the pelvis through the greater sciatic foramen *in company* with the *piriformis* muscle. It extends down toward the popliteal fossa under cover of the gluteus maximus and biceps femoris muscles. Anteriorly it lies upon the external obturator, the gemellus superior, the internal obturator, the gemellus inferior, and the adductor magnus muscles. *Just before reaching the popliteal fossa*, the nerve divides into its two terminal branches, the peroneal and the tibial nerves In the thigh, the sciatic nerve supplies the adductor magnus, the semimembranosus, the biceps femoris and the semitendinosus muscles *g*, *h*, *i*.

The tibial nerve is a more *direct continuation of the* sciatic and it is larger than the peroneal It extends down to the popliteal fossa lying posterior to the popliteus muscle and is immediately posterior to the popliteal artery




Femoral Nerve (distribution)

1a. Rectus femoris.
b. Vastus lateralis.
Vastus intermedius.
c. Pectineus.
Sartorius.
Vastus medialis.
d. Intermediate cutaneous of thigh.
e. Medial cutaneous of thigh.
f. Saphenous nerve.

Sciatic Nerve (distribution)

g. Adductor magnus.
Semimembranosus.
h. Biceps femoris (short head).
i. Semitendinosus and biceps femoris (long head).
j, k. Gastrocnemius.
Plantaris.
Soleus.
Popliteus.
l. Medial sural and sural anastomotic.
m. Posterior tibial.
Flexor hallucis longus.
n. Flexor digitorum longus.
o. Common peroneal.
p. Anterior tibial, extensor digitorum longus and peroneus tertius. Extensor hallucis longus.
q. Peroneus longus and brevis.
r. Cutaneous to foot.

In company with the posterior tibial artery, which is a continuation of the popliteal, it passes under the arch of the soleus and remains in company with the posterior tibial artery until it reaches the space between the medial malleolus and the heel, where it divides into the medial and lateral plantar nerves. It courses through the leg under cover of the soleus and gastrocnemius muscles and is immediately posterior to the tibialis posterior and lateral to the flexor digitorum longus muscles. In the popliteal fossa it supplies the gastrocnemius, soleus, plantaris, popliteus muscles *j*, *k* and gives off the medial sural cutaneous nerve *i*. Lower down, in the leg, it supplies the posterior tibial, the flexor hallucis longus, and the flexor digitorum longus muscles *m*, *n*. The medial and lateral plantar nerves supply sensory fibers to the plantar surface of the foot and toes and muscular fibers to the abductor hallucis, the flexor digitorum brevis, the flexor hallucis brevis, the lumbricales, the interossei and the adductor hallucis. The latter two are mainly supplied by the lateral plantar nerve.

The common peroneal nerve extends down lateralward toward the head of the fibula and circles the neck of the fibula in a subcutaneous position immediately overlying the peroneus longus muscle. It arises from the 4th and 5th lumbar and 1st and 2nd sacral nerves. Beneath the peroneus longus the nerve divides into the superficial and the deep branches. The common peroneal gives off the sural anastomotic which joins the medial sural to form the sural nerve supplying the lateral aspect of the foot and leg.

The deep peroneal nerve passes under the extensor digitorum longus along the anterior aspect of the interosseous membrane, in company with the anterior tibial artery, and extends to the ankle joint, where it divides into lateral and medial terminal branches The nerve lies on the lateral side of the anterior tibial artery at first, then it crosses the artery, and again lies on its lateral side at the ankle. The deep peroneal supplies muscular and cutaneous branches. In the leg it innervates the tibialis anterior, extensor digitorum longus, peroneus tertius, and extensor hallucis proprius. Its cutaneous distribution supplies an area including contiguous portions of the big and second toes, and a corresponding portion of the dorsum of the foot.

The superficial peroneal nerve extends down between the peroneus longus and extensor digitorum longus, and at the junction of the middle and the lower third of the leg, it becomes superficial and divides into the medial and intermediate dorsal cutaneous nerves. In its course through the leg it supplies the peroneus longus and brevis. The superficial peroneal nerve supplies the big toe, the second, the third, the fourth, one half of the 5th toe, the corresponding portion of the dorsum of the foot, and the anterolateral aspect of the leg to about the junction of the upper and middle third

*Axillary vessels and the brachial plexus:*

The axillary artery is usually divided into three parts on the basis of the relationship of the vessel to the pectoralis minor muscle. The first portion is above the pectoralis minor, the second, is immediately underneath the muscle and the third portion extends from the lower end of the pectoralis minor to the lower border of the teres major. This portion of the axillary artery is superficial and can be palpated with ease under the skin of the axilla. On the posterior aspect of the second portion of the axillary artery is the posterior cord of the brachial plexus. On its medial side is the medial cord which also separates the artery from the brachial vein. On the lateral side is the lateral cord. These relationships vary somewhat from specimen to specimen. The third portion of the axillary artery is laterally bounded by the median nerve, medially by the ulnar, median brachial and antibrachial cutaneous nerves. On the medial aspect also is the axillary vein which may consist of one or two vessels. Behind the artery are the radial and axillary nerves.

*Radial nerve and superior profunda artery:*

The radial nerve in its course on the posterior aspect of the humerus in the radial groove is accompanied by the superior profunda artery. This is a branch of the brachial artery arising just below the teres major muscle. It is in a position medial and inferior to the nerve and can be left intact if the nerve is carefully separated along its epineural lining.

*Superior ulnar collateral artery and ulnar nerve:*

The superior ulnar collateral artery is a branch of the brachial a little below the middle of the arm. It extends down between the medial epicondyle and the olecranon in company with the ulnar nerve and it ends under the flexor carpi ulnaris muscle anastomosing with the posterior ulnar recurrent artery. In dissections of the ulnar nerve about the elbow this artery is found to be in the connective tissue lining in close proximity of the nerve. If the nerve is separated along its epineural lining, then the artery is left intact and no bleeding is encountered as a result of injury to it.

*Relations in the antecubital fossa:*

The biceps tendon is most lateral, the brachial artery is medial to the tendon, the median nerve is medial to the artery. In the lower portion of the fossa, the ulnar head of the pronator teres separates the artery from the nerve.

*Nerve-vessel relations at the wrist:*

The median nerve at the wrist is not accompanied by blood vessels of significant size. The ulnar nerve, however, is accompanied by the ulnar vessels. The ulnar artery and vein are in a position anterior and lateral to the nerve; the nerve is the most anterior.

*Relations of femoral nerve, artery and vein:*

Immediately below the inguinal ligament the nerve is in a most lateral position. The artery is in the middle and the vein is in a medial position. In its course on the anterior aspect of the upper half of the thigh, the femoral artery is accompanied by the saphenous nerve which is on its lateral aspect.

*(Continued on page 414.)*

Section through the lower third of the pelvis shows at *a* the femoral nerve, artery and vein. Immediately lateral to *a* is a cross section of the femur and anterior to this bone lie the glutei medius and minimus. Immediately under the skin and further anteriorly are the tensor fasciae latae and the sartorius muscles. Medial to *a* is the pectineus muscle; *b* is the obturator nerve, immediately lateral to the external obturator muscle, which in turn is lateral to the internal obturator on the medial posterior surface of which we see the pudendal nerve, *d*. The sciatic nerve at *c* is in front of the gluteus maximus. Immediately anterior to it is the quadratus femoris. The levator ani surrounds the midline structures (rectum, uterus, bladder).

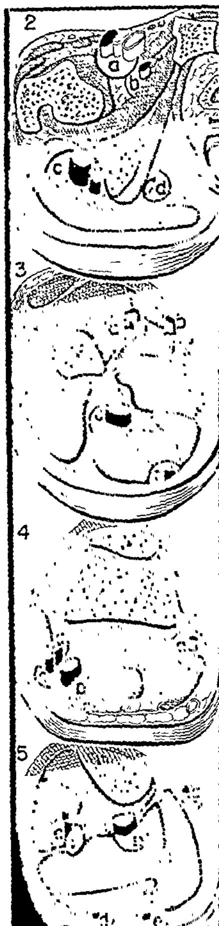
A section of the thigh in its middle third is shown in *3*. At *a* is the saphenous nerve and the femoral vessels; immediately medial and anterior to it is the sartorius muscle; laterally the quadriceps femoris with oval-shaped rectus femoris are seen in a most anterior position. Immediately posterior and medial to *a* is the oval-shaped adductor longus and the quadrangular adductor magnus, medial to which is the gracilis muscle. On the posterior aspect of the thigh, the hamstring muscles, are the semimembranosus, the semitendinosus medially and the biceps laterally. The sciatic nerve is shown at *c* and its branch, the posterior femoral cutaneous, is also seen at *c* near the skin surface.

A cross section through the middle of the popliteal fossa is seen in *4*. At *b* is seen the tibial nerve, at *d* the peroneal nerve. The muscular structure immediately lateral and anterior to *c* is biceps femoris and a portion of the plantaris can be seen immediately posterior and lateral to the femur. Medial to *b* is the semimembranosus muscle, and the tendon of the semitendinosus posteriorly. The oval shaped muscle on the posterior medial aspect is the sartorius with a tendon of the gracilis muscle immediately on its lateral aspect.

Cross section through the junction of the upper and middle third of the leg is seen in *5*. At *a* is the saphenous nerve with the gastrocnemius muscle immediately lateral to the same. The lateral head of the gastrocnemius may be seen immediately anterior to *e* and *d*. The soleus is the muscle between *b* and *c* on the one hand, and the gastrocnemei posteriorly. The posterior tibial is at *b*, and *c* is the deep and superficial peroneal nerves. The anterior tibial, the extensor digitorum longus, the hallucis longus, and the peronei longus and brevis may be seen anteroposteriorly in that order.

## Femoral and Sciatic Dissections

Exposure of the femoral nerve just below the inguinal ligament is shown in *1*. The incision used is that in *4* After incising the skin and subcutaneous tissue, immediately below the level of the inguinal ligament, the femoral nerve may be found lateral to the pulsating femoral artery. One may be able to demonstrate the muscle tissue between the femoral artery and nerve, which is a portion of the psoas major The downward exposure of the femoral is facilitated by retracting the sartorius muscle which crosses the femoral




2a. *Femoral nerve, artery and vein.*
b. Obturator nerve next to obturator *externus.*
c. Sciatic nerve anterior to gluteus maximus
d. Pudendal nerve next to internal obturator.

3a. Saphenous.
b. *Medial cutaneous of thigh.*
c. *Sciatic and posterior femoral cutaneous*

4a. Saphenous.
b Tibial
c Sural cutaneous
d. Common peroneal.

5a. Saphenous
b Tibial.
c. Deep peroneal.
Superficial peroneal.
d Sural anastomotic.
e. Medial sural.

nerve and its branches. In *1a* the sartorius muscle is retracted; *b* is the connective tissue covering over the femoral artery and vein; *c* is the femoral nerve which begins to branch into muscular and cutaneous branches; *d* is the branch of the femoral artery, the circumflex femoralis lateralis.

In *2* exposure of the sciatic nerve on the posterior aspect of the upper thigh is shown in the reversed hockey stick incision *a* in *6*. Immediately below the level of the gluteus maximus the nerve is covered by subcutaneous tissue and skin. After incision of the skin the nerve may be exposed in the groove between the ischial tuberosity and the greater trochanter and it may be palpated and rolled under the finger. The exposure of the nerve into the sciatic foramen necessitates incision of the gluteus maximus muscle. Exposure of the nerve toward the popliteal fossa necessitates retracting the long head of the biceps femoris laterally. When the nerve is exposed, from the sciatic notch down to the middle third of the thigh, it is found lying on the obturator externus, the gemellus inferior and the adductor magnus muscles Portions of it are covered by the gluteus maximus, and the long head of the biceps. At *a* in *2* the gluteus maximus and the piriformis are retracted. At *b* the superior gluteal artery is seen; *c* is the sciatic nerve; *d* is the retracted long head of the biceps and the middle circumflex artery; *e* retracts the short head of the biceps; and *f* is the perforating artery.

In *3*, exposure of the sciatic nerve in the popliteal fossa and its two terminal branches, the tibial and common peroneal is shown. After incision of the skin, as shown in *6b* the sciatic nerve may be found just posterior to the popliteal artery and vein. It usually divides into the tibial and peroneal nerves, high up in the popliteal space. A branch given off from the tibial is shown at *e*, the medial sural cutaneous nerve. At *d* the common peroneal also gives off an anastomotic branch which unites with the medial sural to form the sural cutaneous nerve. The common peroneal is immediately under the skin and subcutaneous tissue, about the head and neck of the fibula, on the lateral aspect of the leg just below the knee. It can be easily palpated and rolled under the finger. It lies on the peroneus longus. *3a* shows the retraction of the biceps; *b* shows retraction of the semimembranosus and semitendinosus; *c* is the popliteal artery, vein and nerves, *d* is common peroneal nerve and the peroneal anastomotic being given off; *e* is the medial sural.

In *5* and *7* a quick review of the surface anatomy of the anterior and posterior thigh and the posterior leg are given In *5*, beginning at the medial end and extending laterally, one sees the gracilis, the adductor longus, the pectineus, the psoas, and the iliacus muscles. Crossing these structures is the sartorius, the most lateralward is the tensor fasciae latae, and immediately below is the rectus femoris. In *7* the biceps is seen at *a;* the tensor fasciae latae at *b*. The vastus lateralis and the medial hamstring muscles may be seen on the medial aspect of the thigh and knee These are the semimembranosus, the semitendinosus, gracilis and sartorius. In the leg the gastrocnemius and the Achilles tendon are shown




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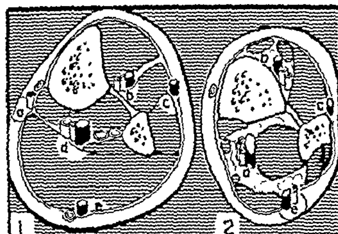
... and nerve. d. Common peroneal and sural anastomatic. e. Medial sural

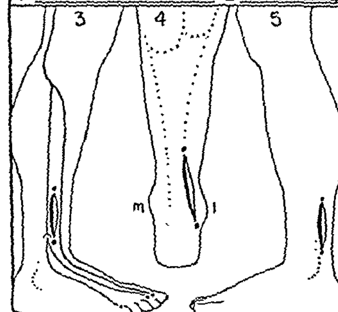
In *1* and *2* cross sections of the leg, just above the ankle, are given. In *1a* is the saphenous nerve and vein. In *1b* and *2b* the deep peroneal is shown between the tibialis anterior, medially and the extensor hallucis longus and extensor digitorum longus, laterally. The cutaneous branch of the superficial peroneal is visualized at *c* immediately under the skin and subcutaneous tissue. The posterior tibial nerve is at *d* accompanied by the posterior tibial artery. The sural cutaneous nerve is seen at *e; immediately in front of it is the gastrocnemius muscle and soleus muscle. 2* is a cross section of the leg just above the ankle. The deep peroneal is at *b* between the tendon of the anterior tibial, the extensor hallucis longus and extensor digitorum longus, accompanied by the anterior tibial artery and vein. The superficial peroneal nerve is at *c* immediately under the skin and subcutaneous tissue and overlying the peroneus longus and brevis muscles. The posterior tibial artery and nerve at *d* lie just medial to the flexor hallucis longus and between the flexor digitorum longus anteriorly and the soleus and gastrocnemius posteriorly. The sural cutaneous and deep saphenous vein are found at *e*.

In *3*, *4* and *5* the position of the incisions for denervating the foot are shown. In *3* that for the deep and superficial peroneal nerves; in *4* incision for sural cutaneous; and in *5* the incision for the posterior tibial nerve.

In *6* the exposure of the deep peroneal nerve is shown at *c*, with *b* retracting the anterior tibial muscle and *a* retracting the extensor hallucis longus and extensor digitorum longus muscles. The nerve is accompanied by the anterior tibial artery and vein which are somewhat posterior and lateral to the nerve. Through the same incision as shown in *7* the superficial peroneal *nerve may be found under the skin and subcutaneous tissue in a* position somewhat more laterally and overlying the peroneus longus and brevis muscles. In *8* the sural cutaneous shown at *b* with the deep saphenous vein immediately medial to it at *a*, are shown in a subcutaneous position on the lateral aspect of the ankle posteriorly. In *9* the posterior tibial nerve is shown where the incision is indicated at *5*. The flexor digitorum longus is retracted at *a; b* retracts the gastrocnemius and soleus combination; with c being the artery and vein immediately posterior to which is the posterior tibial nerve in black.

Such an operation may be indicated in painful *conditions of the foot*, associated with vascular disease as thromboangiitis obliterans and arteriosclerosis It is important to expose these nerves and to crush them with the least amount of trauma to the tissues, particularly to the blood vessels. With these incisions the various nerves can be exposed and following nerve crushing there is complete numbness of all the toes and the forepart of the foot. The procedure is quite effective in stopping pain *in the distal portion of the foot.*




1, 2. Cross sections above ankle.
- a. Saphenous.
- b. Deep peroneal.
- c. Superficial peroneal.
- d. Tibial.
- e. Sural.

3. Incision for superficial and deep peroneal nerves.

4. *Incision for sural cutaneous.*

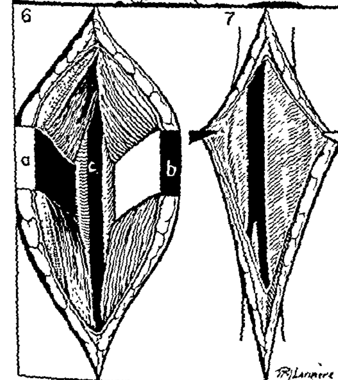
5 Incision for posterior tibial.

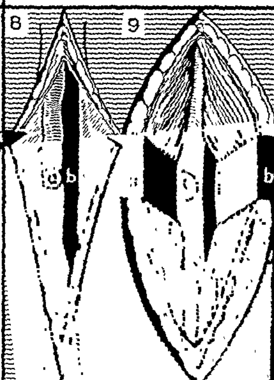
6. Incision in 3. Deep peroneal exposed by retracting.
   - a. *Extensor hallucis longus and extensor digitorum longus and*
   - b. Tibialis anterior.
   - c. Anterior tibial artery and vein immediately underneath the nerve.

7. Through the same incision as in 6, plus 2 cm. lateralward from extensor digitorum longus, superficial peroneal *is seen under the skin.*

8. Through *incision in 4 sural cutaneous* and deep saphenous vein immediately under skin.

9. *Incision in 5 exposing the posterior* tibial nerve just behind the artery and vein.
   - a. Flexor digitorum longus.
   - b. Gastrocnemius and soleus.
   - c. *Posterior tibial vessels and nerve.*



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*Certain Blood Vessel and Nerve Relations (Concluded)*

*Relations in popliteal fossa·*

The sciatic nerve and its direct continuation the tibial nerve are posterior to the popliteal vessels. The popliteal artery is separated from the nerve by the popliteal vein.

*Vessel-nerve relations at the ankle:*

The posterior tibial branch of the popliteal artery accompanies the posterior tibial nerve and is anterior and medial to the nerve. The anterior tibial branch of the popliteal accompanies the deep peroneal nerve and is posterior to the nerve. The sural cutaneous and the lesser saphenous vein are in juxtaposition on the lateral aspect of the lower third of the leg and the ankle. The nerve is usually lateral to the vein.

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